This is to certify that the

thesis entitled

THE TECTONIC EVOLUTION
OF KAMCHATKA PENINSULA, USSR

presented by

Bruce F. Watson

has been accepted towards fulfillment
of the requirements for

M.S. degree in Geological Sciences

Kazuya Fujita
Major professor

Kazuya Fujita

Date July 11, 1985

THE TECTONIC EVOLUTION OF KAMCHATKA PENINSULA, USSR

By

Bruce F. Watson

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Geological Sciences

1985

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ABSTRACT

THE TECTONIC EVOLUTION
OF KAMCHATKA PENINSULA, USSR

By

Bruce F. Watson

Kamchatka Peninsula is composed of ten tectonostratigraphic suspect terranes of oceanic origin which developed during Mesozoic and Cenozoic time. Seven of the terranes consist of an oceanic crustal layer overlain by volcanic arc and sedimentary facies (Kvakhon, Omgon, Sredinny Range, Eastern Ranges, Central Kamchatka Basin, Cape Kamchatka and Southern Kamchatka) while the other three terranes are represented by different facies. The Malkinsk terrane consists of granites and pelitic schists and is probably a metamorphic fragment of a volcanic arc. The Ganal terrane consists of mafic schists, the parent rocks of which were oceanic basalts. The Kronotsky terrane consists of a basaltic sequence of rocks similar in many respects to high alumina island arc basalts. The terranes of Kamchatka are stitched together by several Mesozoic and Cenozoic volcanic arcs while tectonic activity has been controlled by the directions of motion of the Farallon, Izanagi, Kula and Pacific plates.

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INTRODUCTION

Recent studies have demonstrated that large portions of the Circum-Pacific region, including Japan, Northeast Siberia and western North America, are composed of accretionary tectonostratigraphic terranes (e.g., Coney et al., 1980; Csetjey et al., 1982; Fujita and Newberry, 1983; Taira et al., 1983; Jones et al., 1982: McWilliams and Howell, 1982; and many others). Utilizing, the concepts of terrane analysis (Jones et al., 1983; Schermer et al., 1984) these studies delineate individual terranes of a region by the examination of a wide range of information. Geological data concerning paleontology, stratigraphy, lithology and structural geology combined with geophysical data derived from magnetic, gravity and seismic surveys, are used to delineate and to outline the geologic history of each terrane.

Directly related to the events that determined the current configuration of the Circum-Pacific terranes are vectoral directions of motion and velocity of oceanic crustal plates that exist or once existed in the Pacific Basin. Recent models concerning these motions (esp. Engebretson, 1982) are being related to periods of orogenesis including volcanic arc activity and quiescence, extensional rifting, emplacement of allochthonous crustal fragments onto continental margins, etc. (Wallace and Engebretson, 1984; Engebretson et al., 1984; Henderson et al., 1984; Page and Engebretson, 1984; and others). Finally, combining the information about the geologic histories of each terrane with the plate motion vector data allows for the determination of a tentative geologic model that describes the plate tectonic evolution of the region of interest.

Kamchatka Peninsula, located in the northwest Pacific Ocean (fig. 1) is a part of the Circum-Pacific region that has not yet been interpreted in the terms of accretionary tectonics. Kamchatka is part of northeast Siberia and has been examined in detail by Soviet geologists who have described volcanic arc, oceanic and continental facies within the boundaries of the peninsula. The rocks are predominantly of Cretaceous and Tertiary age, although Jurassic, and possibly Devonian, assemblages may be present (figs. 5a and 5b). The origins of the various rock types are commonly explained in the terms of the formation and development of geosynclinal regimes (e.g., Avdeiko, 1971; Gnibidenko et al., 1974; Shapiro, 1981).

Preliminary examination of the geological and geophysical data concerning Kamchatka Peninsula reveals several different geological provinces, each of which represents a suspect tectonostratigraphic terrane. It is the purpose of this thesis to examine in detail the available data on Kamchatka Peninsula in order to determine the character and extent of the suspect terranes and to develop a plate tectonic model outlining the tectonic

Figure 1 - Regional map of the northwest Pacific Ocean

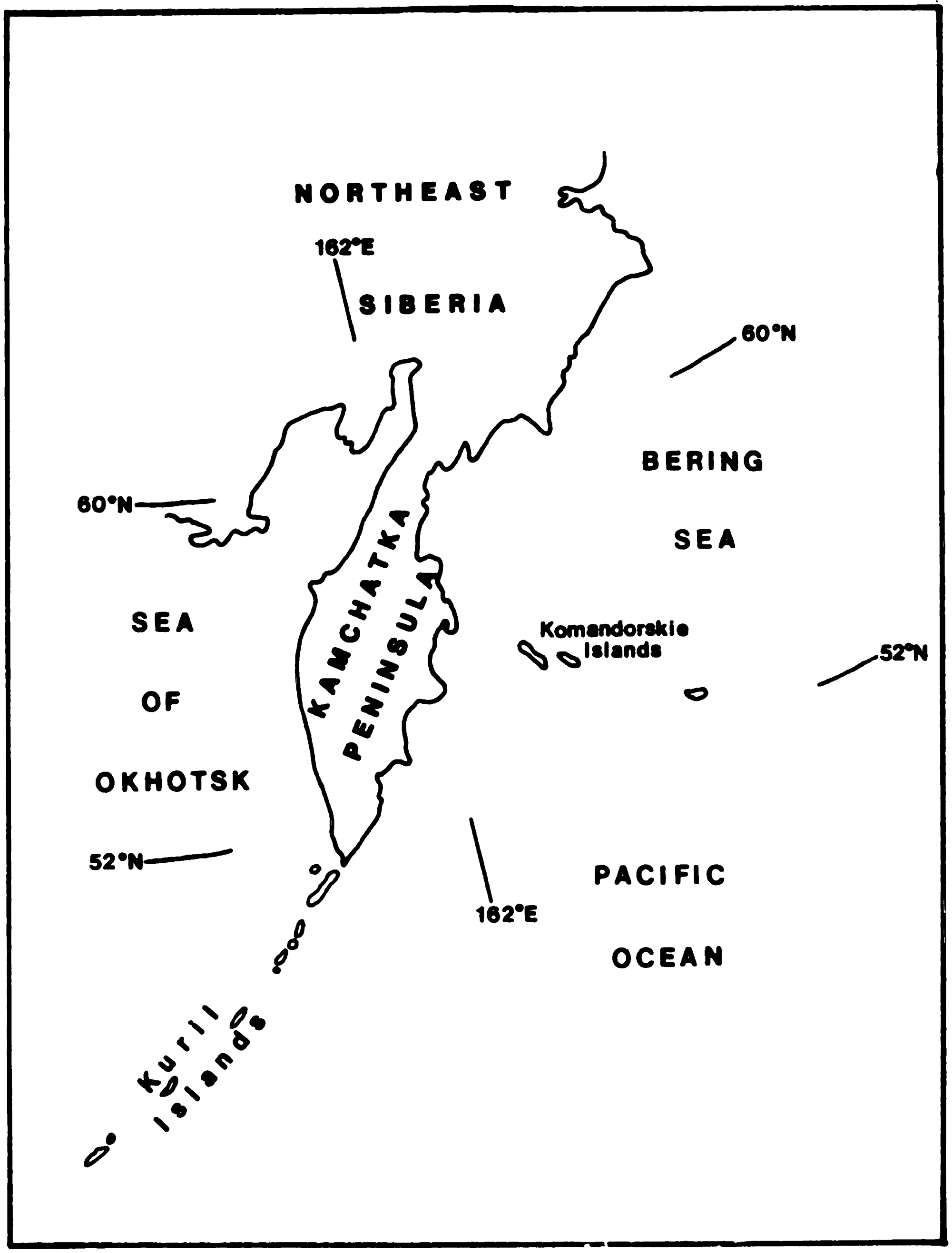
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Figure 1

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evolution of Kamchatka Peninsula. The methodology used in the analysis is outlined in a following section.

The study of Kamchatka Peninsula is important for two primary reasons. First, because of the structural position of the peninsula, an understanding of how Kamchatka developed through time is important for constraining models for the tectonic development of nearby areas. These areas include in particular, the Kuril and Aleutian arcs, the Sea of Okhotsk and northeastern Siberia. Secondly, determination of the sequence of plate tectonic events will provide constraints for motions of oceanic crustal plates in the northwestern Pacific Basin.

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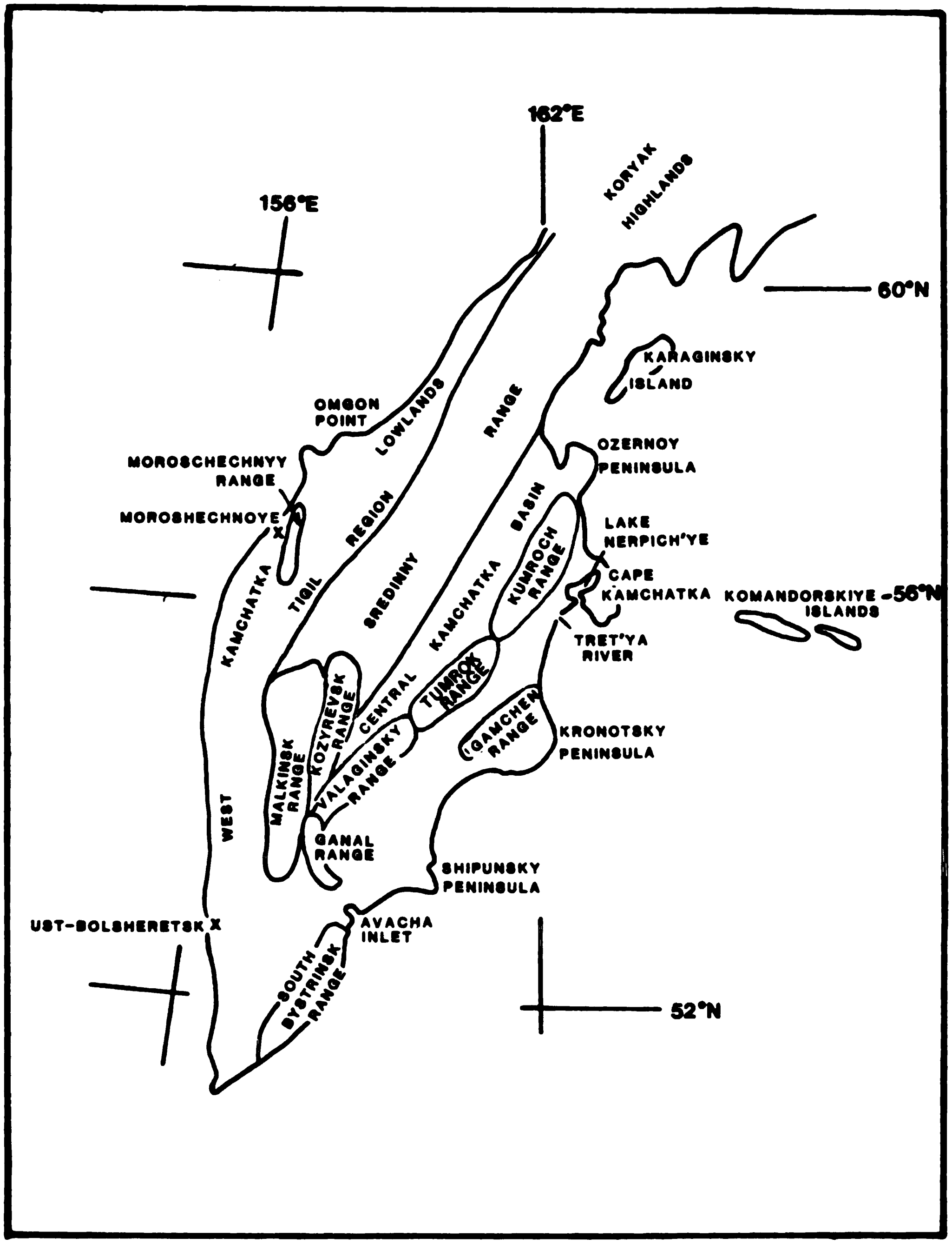
GEOGRAPHIC OVERVIEW

Kamchatka Peninsula is dominated by two major mountain ranges. The Sredinny (Central) Range extends through the center of the peninsula, from the Malkinsk block in the south to the Koryak Highlands in the north (fig. 2). A wide variety of rock types are exposed along the length of the Sredinny Range. The Malkinsk and Kozyrevsk Ranges are often included as part of the Sredinny Range (fig. 2). The Malkinsk Range is predominantly a metamorphic terrain of silicic rocks with large exposures of granitic batholiths. The Kozyrevsk Range consists of mafic and intermediate igneous rocks of oceanic and volcanic arc origin. The majority of the Sredinny Range north of the Kozyrevsk Range consists of exposures of young volcanic and sedimentary rocks. Rocks similar to those found in the Kozyrevsk Range are exposed in the Sredinny Range in the neck of Kamchatka. Many volcanoes are found in the central and northern regions with maximum altitude reaching 4570 meters.

The Eastern Ranges lie in the eastern portion of the peninsula (fig. 2) and can be subdivided, from south to north, into the Ganal, Valaginsk, Tumrok and Kumroch Ranges. Rock types exposed along the length of the ranges, except for the Ganal Range, are very similar and consist of volcanic and sedimentary facies. The Ganal Range is a metamorphic terrain of mafic rocks.

Between the Sredinny Range and the Eastern Ranges lies

Figure 2 - Geographic map of Kamchatka Peninsula


162°E
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NERPICH'YE
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KUMROCH
RANGE
CAPE
KAMCHATKA
KOMANDORSKIYE
ISLANDS
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KAMCHATKA
SREDINNY
KAMCHATKA
TRET'YA
RIVER
KOZYREVSK
RANGE
CENTRAL
TUMROK
RANGE
GAMCHEN
RANGE
KRONOTSKY
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the Central Kamchatka Basin, a relatively flat area that is filled in with young alluvial and fluvial sediments. The largest volcanoes of Kamchatka are found in the central area of this basin. Mount Klyuchevsk reaches a height of 4750 meters and is currently active.

The West Kamchatka lowlands lie between the Sredinny Range and the Sea of Okhotsk (fig. 2). The lowlands extend along the entire western coast of Kamchatka to a northerly latitude of 60 degrees north. Young marine and alluvial sedimentary rocks are common. Most of the river drainage from the Sredinny Range flows west across the lowlands and into the Sea of Okhotsk.

Finally, the South Bystrinsk Range is located on the eastern coast of the southern tip of Kamchatka (fig. 2). The range is geologically and morphological distinct from the Eastern Ranges and is therefore not included as part of them. The rock types exposed are identical to what is found in the central and northern regions of the Sredinny Range. Because of the facies similarities, the South Bystrinsk Range is sometimes included as the southerly continuation of the Sredinny Range.

Several geographic features in the vicinity of the northwestern Pacific Basin and northeastern Siberia are directly or indirectly related to Kamchatka Peninsula. Two currently active island arcs, the Aleutian and the Kuril, are located to the east and south of Kamchatka, respectively (figs. 2 and 3). The Aleutian arc separates the Beri

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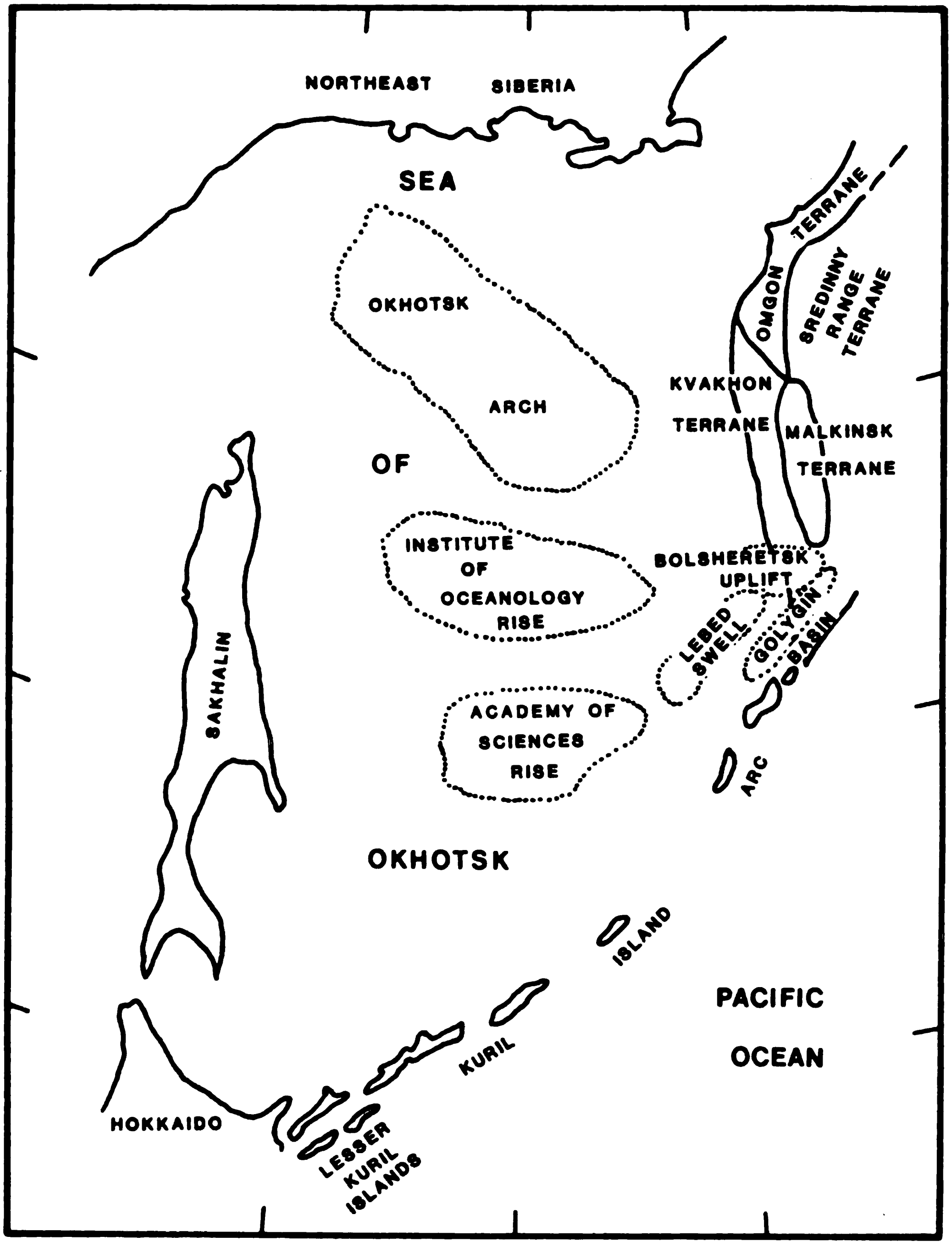
the Bering Sea from the Pacific Ocean and extends from the Alaska Peninsula to Cape Kamchatka. The eastern two-thirds of the arc is presently underthrust by the Pacific plate while transcurrent motion with oblique underthrusting occurs along the western one-third of the arc (Cormier, 1975; Newberry, 1983). The Kuril arc extends from north of Hokkaido Island onto the southeastern margin of Kamchatka Peninsula and is currently being underthrust by the Pacific plate. The northern extent of the arc on Kamchatka correlates with the junction of the Aleutian arc and Cape Kamchatka, i.e., at the Kuril-Kamchatka trench junction.

To the north of Kamchatka lies the Koryak Highlands of northeastern Siberia (fig. 2). Morphologic features of Kamchatka, in particular, the Sredinny Range, extend into the Highlands. This area is mountainous and has a very complex and diverse geology, consisting of predominantly oceanic and volcanic arc facies.

West of Kamchatka lies the Sea of Okhotsk. Interpreted results of seismic reflection and refraction work and dredgings indicates many structural features are present, several of which are believed to be related to features on Kamchatka (Gnibidenko and Khvedchuk, 1982). The most relevant features include the Academy of Sciences Rise, the Lebed Swell, the Bolsheretsk uplift and the Institute of Oceanology Rise (fig. 3).

Figure 3 - Tectonic features of the Sea of Okhotsk
(after Gnibidenko and Khvedchuk, 1982)


NORTHEAST SIBERIA
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INSTITUTE
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OCEANOLOGY
RISE
ACADEMY OF
SCIENCES
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SAKHALIN
OMGON
TERRANE
SREDINNY
RANGE
TERRANE
KVAKHON
TERRANE
MALKINSK
TERRANE
BOLSHERETSK
UPLIFT
LEBED
SWELL
GOLYGIN
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ISLAND
KURIL
PACIFIC
OCEAN
HOKKAIDO
LESSER
KURIL
ISLANDS

Figure 3

METHODOLOGY

The methods used to determine the character and extent of the terranes of Kamchatka are found in Jones et al. (1983) and are summarized below. Terranes are defined as "fault bounded geologic entities of regional extent, each characterized by a geologic history that is different from contiguous terranes" (Jones et al., 1983). The uniqueness of the stratigraphic column, therefore, is the main criterion by which a terrane is identified. Paleontological, stratigraphic and lithologic data are used to determine the stratigraphic sequence of a terrane while geophysical data and data on major faults or suture zones are used to delineate the extents of a suspect terrane. The clarity with which a terrane or group of terranes is identified is dependent upon the amount and quality of the aforementioned controls.

The methodology used in the thesis for the terrane analysis consisted of three steps. First, the literature was studied to determine the stratigraphy of the regions of Kamchatka, allowing for a tentative delineation of terranes. Next, data on major faults, fault zones and suture zones in conjunction with available gravity and magnetic data allowed for the determination of the boundaries of the terranes. Finally, general examination of the geology and geophysics of tectonic features surrounding Kamchatka provided the final constraints on the

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character and extent of the terranes. This final step also involved the development of a tentative model for the plate tectonic evolution of Kamchatka Peninsula. Constraints for the model are provided not only by the elements of the tectonic history of each individual terrane considered as a whole but also by models for the relative motion of oceanic plates in the Pacific Basin during Mesozoic and Cenozoic time. Figure 27 is a tectonic/geology correlation chart that summarizes the age, geology and tectonic activity of the terranes and is presented after the geological discussion.

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SOURCES OF UNCERTAINTY

Several factors limit the precision of the conclusions reached in this study. Since the majority of the geological data on Kamchatka are extracted from Soviet references, an important element affecting the accuracy of conclusions presented in this thesis are the differing methods of interpretation of geologic data by Soviet and western geoscientists. Commonly, there is a tendency by Soviet geoscientists to describe geological phenomenon in the terms of geosynclines, the concepts of which were outlined by Aubouin (1965) and Kay (1951), a distinct contrast to conventional plate tectonic theory originally outlined in detail by Heirtzler et al. (1968), Isacks et al. (1968), Le Pichon (1968) and Morgan (1968). The major difference in these two approaches to the development of regional tectonic models is the basis of geosynclinal theory on only vertical crustal motions in contrast to horizontal crustal plate motions that provide the basis for modern plate tectonic theory. The emphasis is thus placed on vertical, and not horizontal stress regimes and motions, in Soviet interpretations. Consequently, data on geological structures that resulted from horizontal maximum stresses (esp., thrust faults) are not always described in the literature, or are described from a vertical stress regime and motions point of view. Information regarding them can only be obtained indirectly by interpretation which can lead to in

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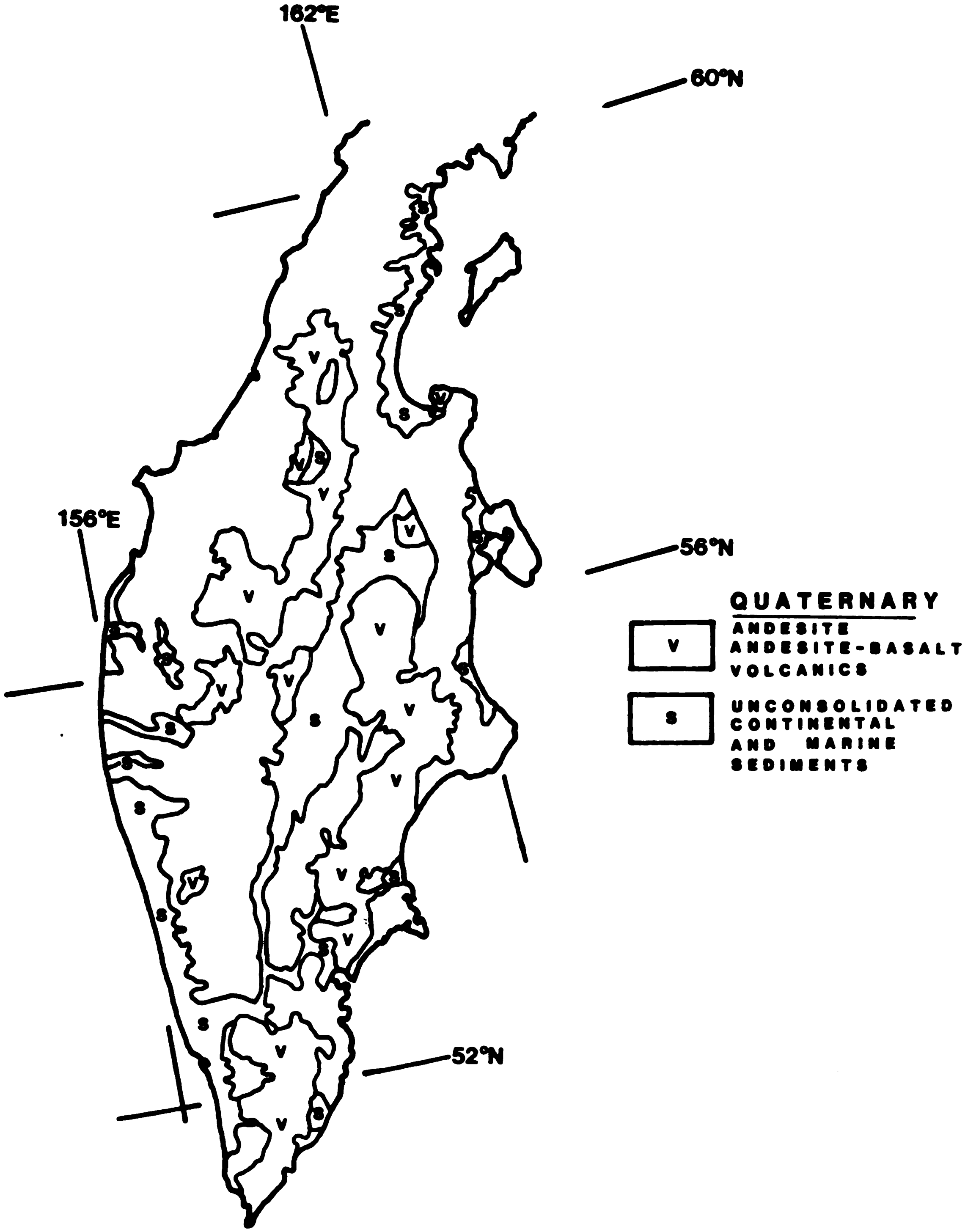
Secondly, it is often difficult to separate raw data collected in the field or the laboratory from conclusions and extrapolations drawn in the paper or by other workers referenced in the paper. In addition, scales and directions usually left off of geological maps can render otherwise good information unreliable and possibly unuseable.

Lack of geological and paleomagnetic data increases the uncertainties of the tectonic model. Available geologic data density varies greatly throughout Kamchatka Peninsula, ranging from sparse in the northern and western areas to adequate in the central and eastern areas. Thus, terrane boundaries are not always determined with precision and some terranes may actually be composite terranes. Extensive Quaternary volcanic and clastic deposits found throughout the peninsula (fig. 4) obscure the older formations and thus limit exposures of important geological features. Paleomagnetic pole data that could very usefully be used to determine relative motions, if any, between various regions of Kamchatka or between these regions and associated areas of geological interest have not been determined. Thus, it is possible that relative motions between various regions have occurred. These possible motions include, in particular, syn- and post- accretionary terrane translation, similar to what is observed to have occurred in certain western North American terranes, e.g.,

Figure 4 - Quaternary geology map of Kamchatka Peninsula


162°E
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Wrangellia (Jones et al., 1977).

The data sources used in the study include Soviet literature and maps, primarily in translation but some in Russian, and several international geological journals. The major sources of literature include Doklady Akademii Nauk USSR, International Geology Review, Geotectonics, Lithology and Mineral Resources, Tectonophysics, Marine Geology and Pacific Geology. Translations have also been obtained from the United States Geological Survey. Several different geological and tectonic maps were also referenced.

Figure 5a - General geologic map of Kamchatka Peninsula

Figure 5b - Geological nomenclature

TERTIARY

clastics

Qs	-	Quaternary
Tmp	-	Miocene and Pliocene
Tm	-	Miocene
Tom	-	Oligocene and Miocene
To	-	Oligocene
Te	-	Eocene
Tpo	-	Paleocene to Oligocene
Tpe	-	Paleocene and Eocene

volcanics

Qv	-	Quaternary andesite and basalt
Tmpv	-	Miocene and Pliocene andesite and basalt
Tmu	-	Miocene undifferentiated volcanics
Tmv	-	Miocene andesite and basalt
Tomv	-	Oligocene and Miocene andesite and basalt
Tou	-	Oligocene undifferentiated volcanics
Toi	-	Oligocene andesite
Tob	-	Oliogocene basalt
Tpeb	-	Paleocene and Eocene high alumina basalt

JURASSIC/CRETACEOUS

Kl	-	Late Cretaceous clastics
Kli	-	Late Cretaceous andesite
Klo	-	Late Cretaceous ophiolite/upper oceanic layer
Ke	-	Early to middle Cretaceous clastics
JK	-	Late Jurassic arc volcanics and Early Cretacous clastics

MESOZOIC

Mps	-	Mesozoic pelitic schist with abundant granitic intrusions
Mgs	-	Mezozoic greenschist

Figure 5b

TERRANE ANALYSIS

Ten terranes are delineated in Kamchatka through terrane analysis. The terrane map of Kamchatka (fig. 6) and general characteristics (table 1) outline the extent and nature of the terranes.

In this thesis, descriptions of the character and extent of the terranes proceed generally from west to east, in the approximate order of age and appearance in the tectonic model, and are organized as follows.

First, the diagnostic characteristics of the terrane will be given followed by a detailed description of the stratigraphic column, starting with sedimentary suites and followed by igneous formations. The geologic symbols used on the columns are given on Figure 7. An estimate of the approximate location of exposures of the important formations is given on fig. 8a with a list of the formations given in Fig. 8b. Any paleontologic and/or radiometric age data are included in this part of the section. Description of the extent and character of the boundaries of the terranes and the relations of each terrane and surrounding terranes will be discussed. Each section will be concluded with a review of the tectonic history of the terrane. After the discussion of the geology of Kamchatka, the geology of surrounding features of relevant interest and relative plate motion data on oceanic crustal plates of the Pacific Basin will be discussed. The final section will be devoted to the presen

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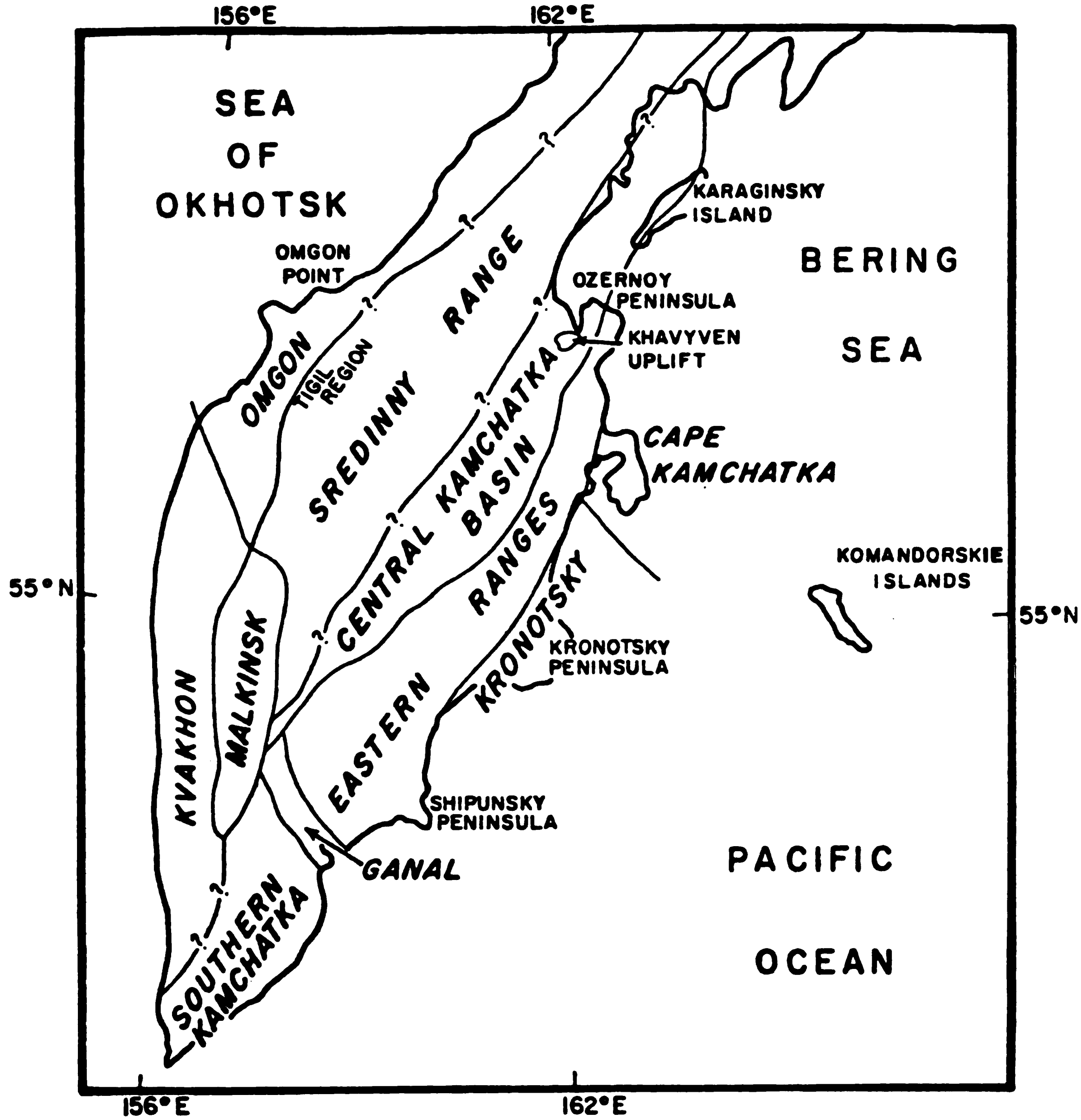
presentation of the model for the plate tectonic evolution of Kamchatka, based on the presented data.

Figure 6 - Terrane map



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CENTRAL KAMCHATKA
BASIN
KARAGINSKY
ISLAND
BERING
SEA
OZERNOY
PENINSULA
KHAVYVEN
UPLIFT
CAPE
KAMCHATKA
KOMANDORSKIE
ISLANDS
55°N
55°N
KVAKHON
MALKINSK
EASTERN
RANGES
KRONOTSKY
KRONOTSKY
PENINSULA
SHIPUNSKY
PENINSULA
GANAL
PACIFIC
OCEAN
SOUTHERN
KAMCHATKA
156°E
162°E

Figure 6

Table 1 - General characteristics of the terranes of Kamchatka

Table 1

Table 1

Terrane Character	Kvakhon	Omgon	Malkinsk	Sredinny Range	Ganal	Southern Kamchatka	Eastern Ranges	Kronotsk	Central Kamchatka	Cape Kamchatka
Type of Basement	arc/ oceanic	arc/ oceanic	arc core (meta-morphic)	arc/ oceanic	oceanic (meta-morphic)	arc ? oceanic ?	arc/ oceanic	arc ?	oceanic?	arc/ oceanic
Age of Oldest Rocks	Late J., Early Cret.	Late J., Early Cret-aceous	Jurassic (Devo-nian?)	Late Cret-aceous	Late Cret-aceous ?	Late Cret-aceous ?	Late Cret-aceous	Late Cret-aceous	Early Tertiary ??	Late Cret-aceous
Method of Dating	Paleo: Inocer-amus	Paleo: Inocer-amus	K - Ar	Paleo: Inocer-amus	K - Ar	Paleo: Inocer-amus	Paleo: Inocer-amus	Paleo.	Paleo.	Paleo.
Predominant Rocks	mafic/ inter. volc., clastics	mafic volc., clastics	felsic, mafic schists	spilite, inter. volc.	amphibo-lite schists	mafic/ inter. volc.	mafic/ inter. volc., clastics	mafic volc.	inter. volc., clastics	mafic/ inter. volc., clastics
Age of Intrusives	Miocene granite	Late J./ E. Cret. granite diorite	Mz.,Cz., granites	Miocene L. Cret. granite	Late Cret. gabbro	Miocene granite	—	Paleog. gabbro	—	Olig. gabbro
Period of Igneous Activity	Late J. to Early Cret-aceous	Late J. to Early Cret-aceous	Jurassic to Late Cret-aceous	L. Cret. Olig. to Miocene	Late Cret-aceous	Olig. to Quat.	L. Cret. Pliocene to Quat.	L. Cret. to Olig.	Olig. to Quat.	Paleo-cene to Quat.
Accretion Date (to which terrane)	middle Cret. Kvakhon	—	middle Cret-aceous Kvakhon	L. Cret. Mal-kinsk	Paleo-cene E. Ran. Malk.	—	Paleo-cene Malk., Ganal	Miocene Eastern Ranges	—	in situ form-ation ?

Figure 7 - Geologic symbols for the stratigraphic columns

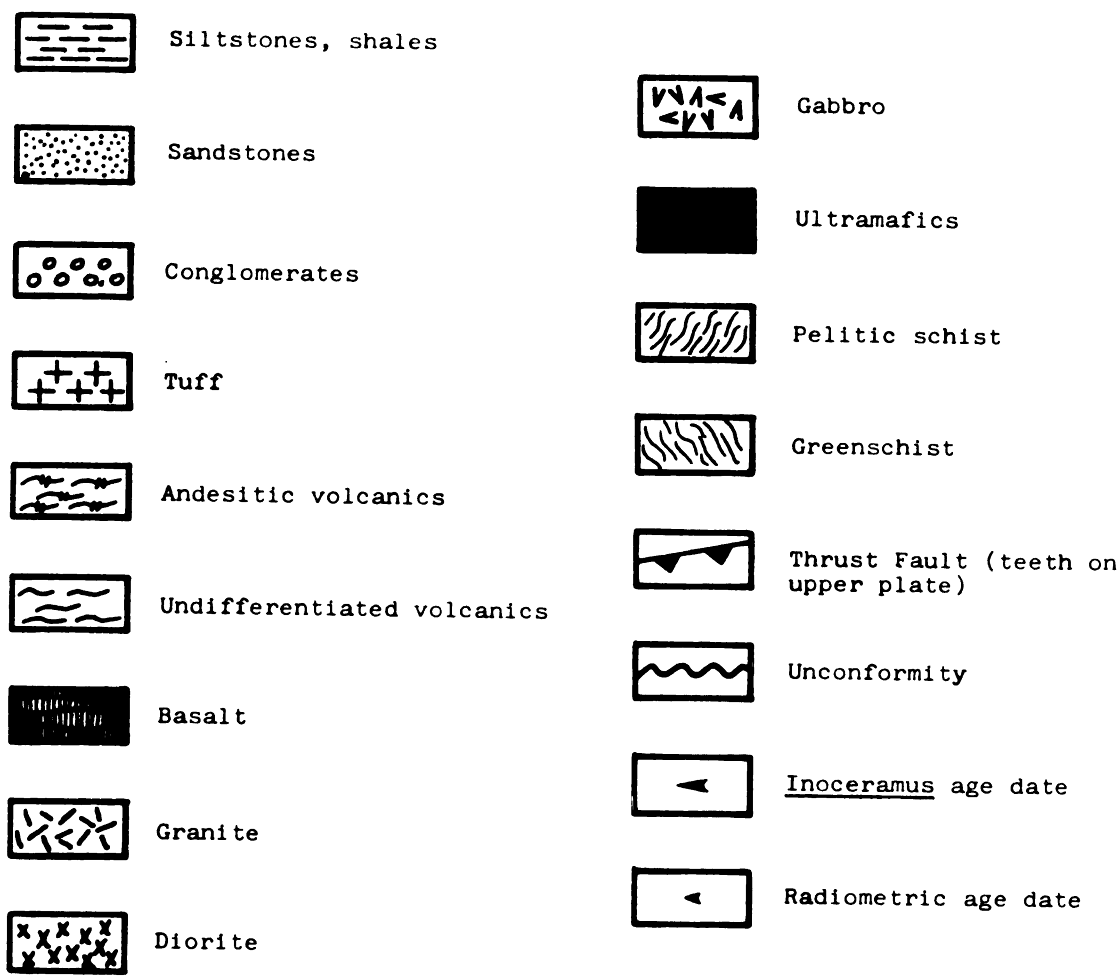
Siltstones, shales
Sandstones
Conglomerates
Tuff
Andesitic volcanics
Undifferentiated volcanics
Basalt
Granite
Diorite
Gabbro
Ultramafics
Pelitic schist
Greenschist
Thrust Fault (teeth on upper plate)
Unconformity
Inoceramus age date
Radiometric age date

Figure 7

Figure 8a - Estimated locations of important formations

Figure 8b - List of formations

Q	Quaternary volcanics and sediments
1	Kvakhon/Kikhchik series'
2	Voyampol/Kavran series'
3	Omgon series
4	Tigil series
5	Kovacha series
6	Cape Kinkilsky suite
7	Iruney series
8	Lesnovo series
9	Kirganik suite
10	Anavgay series
11	Alney series
12	Kolpakova series
13	Malkinsk series
14	Khavyven series
15	Kelmenskaya suite
16	Yelovsk/Kavran series'
17	Valagin series
18	Stenovaya series
19	Khapitsk suite
20	Drozdovsk suite
21	Stanislavsk suite
22	Osipov series
23	Ganal series
24	Alney/Golyga series
25	Afrika series
26	Stolbovsk series
27	Tyushevka series
28	Cape Kamenistyy suite
29	Kronotsky series
30	Bogachevka/Chazhmin series

Figure 8b

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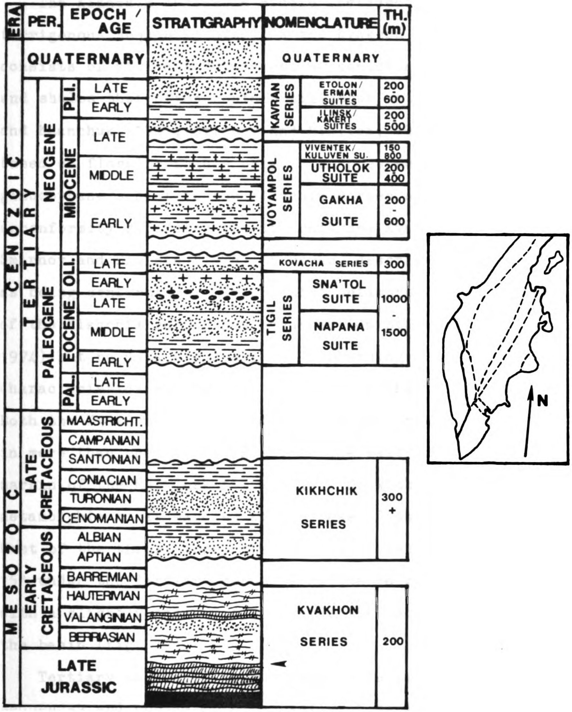
KVAKHON TERRANE

The Kvakhon terrane, located between the Malkinsk terrane and the Sea of Okhotsk (fig. 6), is a Late Jurassic to Early Cretaceous island arc overlain by Late Cretaceous and Tertiary sedimentary sequences (fig. 9). The terrane is bounded on the east by an overthrust zone along which exposures of blueschist mineral assemblages are found and on the north by the "Diagonal suture" (Rotman, 1964).

The basement of the terrane is represented by the Kvakhon series. Outcrops of the lower section of the series are composed of mafic and ultramafic igneous rocks, accompanied by serpentinite, and are exposed along the eastern margin of the terrane. Blueschist metamorphism is indicated by the presence of glaucophane and stilpnomelane (Sidorchuk and Khanchuk, 1981; Shul'diner et al., 1980). The upper section of the series consists of tuffs, shale and sandstone with interbeds of intermediate and mafic volcanics up to 200 meters thick (Gnibidenko et al., 1974; Smirnov and Sinitsa, 1975), which are locally metamorphosed up to the greenschist facies level (Gnibidenko et al., 1974). The age of the Kvakhon series is based on fragments of a Late Jurassic to Early Cretaceous mollusk, <u>Inoceramus</u> (Sidorchuk and Khanchuk, 1981; Smirnov and Sinitsa, 1975). Various species of <u>Inoceramus</u> are often used to date other Cretaceous sedimentary formations throughout Kamchatka Peninsula.

Figure 9 - Stratigraphy of the Kvakhon terrane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TERTIARY
NEOGENE
PLI.
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EARLY
KAVRAN SERIES
ETOLON/ ERMAN SUITES
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ILINSK/ KAKERT SUITES
200 - 500
MIOCENE
LATE
MIDDLE
EARLY
VOYAMPOL SERIES
VIVENTEK/ KULUVEN SU.
150 - 800
UTHOLOK SUITE
200 - 400
GAKHA SUITE
200 - 600
PALEOGENE
OLI.
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EARLY
KOVACHA SERIES
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EOCENE
LATE
MIDDLE
EARLY
TIGIL SERIES
SNA'TOL SUITE
NAPANA SUITE
1000 - 1500
PAL.
LATE
EARLY
MESOZOIC
LATE CRETACEOUS
MAASTRICHT.
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
KIKHCHIK SERIES
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EARLY CRETACEOUS
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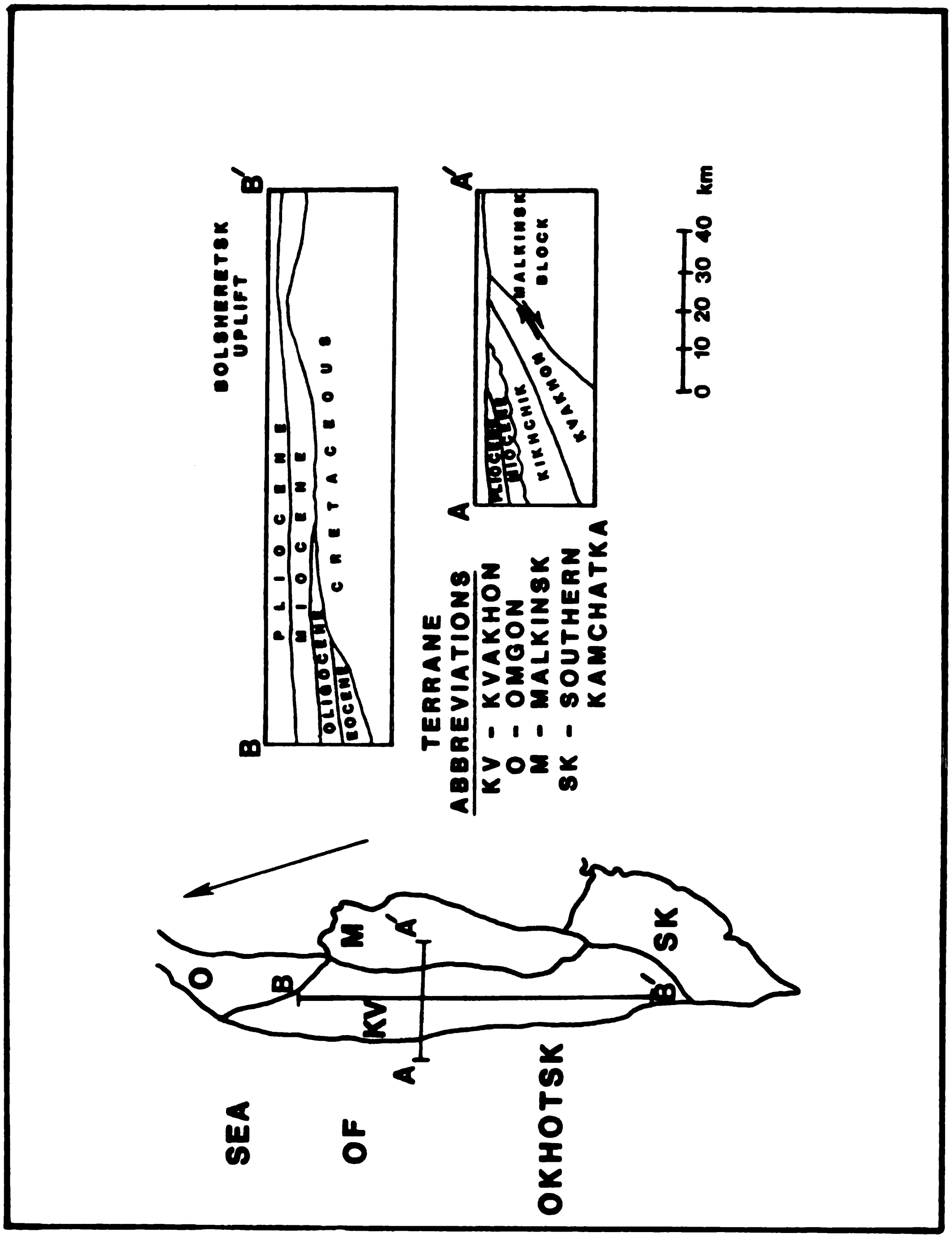
The Kikhchik series, a middle Cretaceous to Santonian terrigenous sequence, overlies the Kvakhon series and consists of at least 300 meters of sandstones, siltstones and shales that often contain siliceous material (Sidorchuk and Khanchuk, 1981; Smirnov and Sinitsa, 1975). The age is based on floral remnants only. The presence of pebbles of glaucophane schist in the Kikhchik series suggests an unconformity separates the Kikhchik and Kvakhon series. Smirnov and Sinista (1975), however, describe the contact as being conformable. Greenschist metamorphism of portions of the Kikhchik series has occurred (Gnibidenko et al., 1974) but no data are available concerning the characteristics and the areal extent of the metamorphism. Both the Kvakhon and Kikhchik series are thrust, possibly in more than one thrust sheet, to the east over the western margin of the Malkinsk block (fig. 10) with the blueschist metamorphic rocks exposed at the base of the thrust sheet. West of the thrust zone, the series dip westerly, 10° to 15° under the Tertiary deposits of the Bolsheretsk basin with a slightly steeper dip towards the northern part of the basin (fig. 10).

Tertiary sequences unconformably overlie the Cretaceous sequences and consist predominantly of marine and continental clastic facies. They are found to the west of the Cretaceous exposures, in the area of the Kvakhon terrane designated as the Bolsheretsk Basin (Gnibidenko et al., 1974; Dmitriyeva, 1981; Fedynsky and Levin, 1970) and

Figure 10 - Cross-section of the Kvakhon and Malkinsk terranes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TERRANE ABBREVIATIONS
KV - KVAKHON
O - OMGON
M - MALKINSK
SK - SOUTHERN KAMCHATKA
BOLSHERETSK UPLIFT
PLIOCENE
MIOCENE
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are well constrained in terms of age by abundant faunal and floral remains. In the southern and central portions of the basin, sequences of Miocene to Quaternary age overlie the Cretaceous rocks and have a thickness of 200 to 1000 meters. However, from the central part of the basin to its northern extents, the Tertiary sedimentary column increases in thickness up to 3500 to 4000 meters and includes Eocene to Quaternary aged rocks. Eocene and Oligocene sequences are therefore exposed only in the northern part of the basin and wedge out in a southward direction.

The Napana and Sna'tol suites, the middle and upper suites of the Tigil series, are exposed only in the northern part of the basin. The lowest suite of the Tigil series, the Khulgun suite, is not found in the Kvakhon terrane but is identified in terranes to the north and east of the Kvakhon terrane. The Napana suite is Early to Middle Eocene in age and consists of sandstones and argillites containing coal beds. The Sna'tol suite, Late Eocene to Early Oligocene in age, consists of sandstones and conglomerates with tuffaceous horizons. The combined thickness of the Napana and Sna'tol suites is 1000 to 1500 meters. The middle to Late Oligocene Kovacha series conformably overlies the Tigil series and consists of siltstones, sandstones and argillite 300 meters thick. Generally, the rocks of the Kovacha series are found in the northern part of the basin but portions of the upper section of the series are found further south, transgressively overlying the older rocks (Dmitriyeva, 1981).

An unconformity separates the Voyampol series from the underlying Kovacha series. The lowest suite of the Voyampol series, the Gakha suite, consists of sandstones and interbedded argillites containing calcareous members and tuffaceous horizons. Conglomerate layers and basaltic volcanic rocks are occasionally found. The suite is 200 to 600 meters thick and of Early to Middle Miocene age. The Middle Miocene Utholok suite, 200 to 400 meters thick, consists of siltstones and argillites with tuffaceous members. The Middle to Late Miocene Viventek and Kuluven suites consist of argillites and siltstones with interbedded tuffs and calcareous horizons, 150 to 800 meters thick.

An angular unconformity separates the Voyampol series from the Kavran series. The Il'insk and Kakert suites, the base of the Kavran series, consists of sandstones, siltstones and shales with layers of tuffs and conglomerates. The thicknesses of the suites ranges from 200 to 500 meters and are Late Miocene to Early Pliocene in age. The Etolon and Erman suites are middle to Late Pliocene in age and consist of 200 to 600 meters of sandstones with interbedded clays, coals and conglomerates. Tuffaceous horizons are also present. Throughout the Kavran series, pebbles of the underlying Cretaceous and Tertiary series are found in conglomerates.

Quaternary fluvial deposits complete the stratigraphic column of the Bolsheretsk Basin and hence, the Kvakhon terrane. Structurally, the Tertiary rocks of the terrane are almost horizontal, with only slight dips to the west, and are gently folded. Intrusives consist solely of Miocene granites located along the east-central margin of the terrane.

The unconformable contact between the Cretaceous and Tertiary sequences exposed along the eastern margin of the terrane is traceable in the subsurface as a refracting horizon (Fedynsky and Levin, 1970; Smirnov, 1971). The horizon dips westward at angles not greater than 10° to 15° but has a slightly steeper dip to the north (Marakhanov and Potap'ev, 1981). The velocity of the refractor ranges from 5.2 to 5.7 km/sec but sometimes reaches 5.9 to 6.0 km/sec (Smirnov, 1971). The range of velocities is indicative of the presence of igneous and/or metamorphic rocks. Smirnov (1971) has noted that no reflecting or refracting horizons are visible in the seismic data beneath the refractor, suggesting again that only igneous and/or metamorphic rocks are present beneath the horizon. One drill hole in the Ust-Bolsheretsk area penetrated an amphibolized gabbro at a depth of 534 meters (Gnibidenko et al., 1974). The association of the gabbro with a particular series cannot be done with certainty. However, the depth correlates with the general position of the refracting horizon in the area.

A major basement uplift, the Bolsheretsk Uplift, is

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located in the southern area of the terrane (fig. 10). It has been identified from seismic and drilling work in the area and is structurally contiguous with features located in the Sea of Okhotsk (Gnibidenko and Khvedchuk, 1982).

The eastern boundary of the Kvakhon terrane is the blueschist/thrust zone that extends along the length of the Malkinsky block. South of the block, the boundary of the Kvakhon terrane becomes buried under Tertiary deposits and may be continuous with the Central Kamchatka Basin (fig. 6). The northern boundary of the Kvakhon terrane is the "Diagonal geosuture" first described by Rotman (1964). The "suture" is a zone of northwesterly trending faults extending from the northern point of the Malkinsk block, northwest into the Sea of Okhotsk just west of the town of Moroshechnoye (fig. 2). Both strike-slip and normal faults are found in the zone. In addition to the presence of the faults, Rotman (1964) indicates other data for the identification of a structural feature. The thickness of Tertiary sequences is much thicker and includes Paleocene strata north of the boundary, as compared to thinner Eocene and younger strata found to the south of the boundary. Cretaceous rocks are found at greater depths north of the boundary than south of the boundary. Strike of folds north of the boundary trend northeast and along the boundary trend northwest while the strike of folds south of the boundary in the Bolsheretsk Basin trend north. In addition, alkaline basalt volcanoes of Neogene age common in

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in western Kamchatka are absent south of the zone.

In summary, the tectonic history of the Kvakhon terrane commences in Late Jurassic time with the onset and development of island arc activity, designated as the Kvakhon arc. The arc associated volcanic and sedimentary rocks, the Kvakhon series, were deposited onto oceanic crust that is now exposed along the eastern margin of the terrane. Taking into account the Late Jurassic to Early Cretaceous age of the arc formations, the oceanic layer is Jurassic, or older, in age. Arc activity ceased in Early to middle Cretaceous time and was followed by a period of uplift. Deposition of the Kikhchik series occurred during middle Cretaceous to Santonian time. Late Cretaceous uplift produced an unconformity between Cretaceous and Tertiary rocks. Deposition of shallow marine and continental facies commenced in the northern part of the basin in Eocene time. Southward transgression of the depositional environment occurred in Late Oligocene through Miocene time and was the period of greatest subsidence of the basin. These formations, including the rest of the Miocene strata and the Pliocene strata, were deposited in the Bolsheretsk basin. The presence of tuffs in the Neogene sequence indicates the basin was in close proximity to an active island arc during this time. This fact, in addition to the lack of tectonic activity in the Kvakhon terrane at this time (i.e., a quiet period of sedimentation), suggests the Bolsheretsk basin may have been

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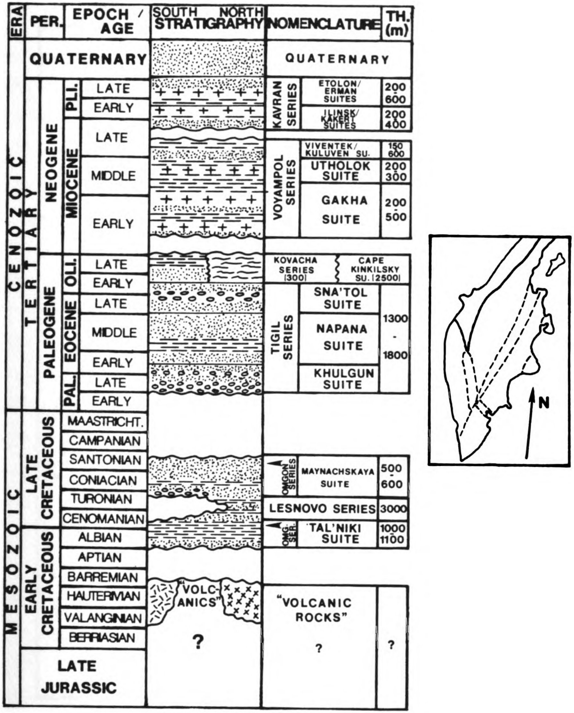
been a back arc basin, with an arc trench system located to the east. During Late Pliocene or Quaternary time, the terrane was uplifted above sea level, leading to the current fluvial sedimentation.

OMGON TERRANE

The Omgon terrane lies to the north of the Kvakhon terrane, across the "geosuture". The terrane has a thick Cretaceous and Tertiary sedimentary column overlying either oceanic or island arc igneous suites of Mesozoic age (fig. 11). The terrane is bounded on the south by the "diagonal suture", on the east by an overthrust zone indistinctly exposed, and extends north into the Kamchatka Isthmus.

Sparseness of available data on this region of Kamchatka prevents a conclusive determination of the true nature of the basement rocks. The oldest referenced rocks are Early Cretaceous (Barremian or older) "volcanic rocks" beneath the sedimentary column at Omgon Point whose specific nature is not described (Voronkov and Smirnov, 1971). An unconformity separates the volcanic rocks from the overlying sedimentary rocks. Krasny (1964) lists outcrops of diorite and granite, both of Cretaceous age, at Omgon Point and in the Moroschechnyy Range, respectively. Cretaceous diabase outcrops one to two kilometers east of the exposures of the granite. Neither the nature of the contact between these rocks and overlying sedimentary sequences nor the method of their dating is given. Exposed in the basement of the Kinkilskaya anticline, located along the western margin of the isthmus of Kamchatka (fig. 12), is a sequence of Early Cretaceous mafic effusives (Gnibidenko et al., 1974). The method of dating of these basement rocks is not stated but is probably inferred from

Figure 11 - Stratigraphy of the Omgon terrane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BARREMIAN
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VALANGINIAN
BERRIASIAN
LATE JURASSIC
"VOLCANICS"
?
QUATERNARY
KAVRAN SERIES
ETOLON/ ERMAN SUITES
200 - 600
ILINSK/ KAKERT SUITES
200 - 400
VOYAMPOL SERIES
VIVENTEK/ KULUVEN SU.
150 - 600
UTHOLOK SUITE
200 - 300
GAKHA SUITE
200 - 500
KOVACHA SERIES (300)
CAPE KINKILSKY SU. (2500)
TIGIL SERIES
SNA'TOL SUITE
NAPANA SUITE
KHULGUN SUITE
1300 - 1800
OMGON SERIES
MAYNACHSKAYA SUITE
500 - 600
LESNOVO SERIES
3000
OMG. SER.
TAL'NIKI SUITE
1000 - 1100
"VOLCANIC ROCKS"
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Figure 11

Figure 12 - Structural features of the Omgon terrane

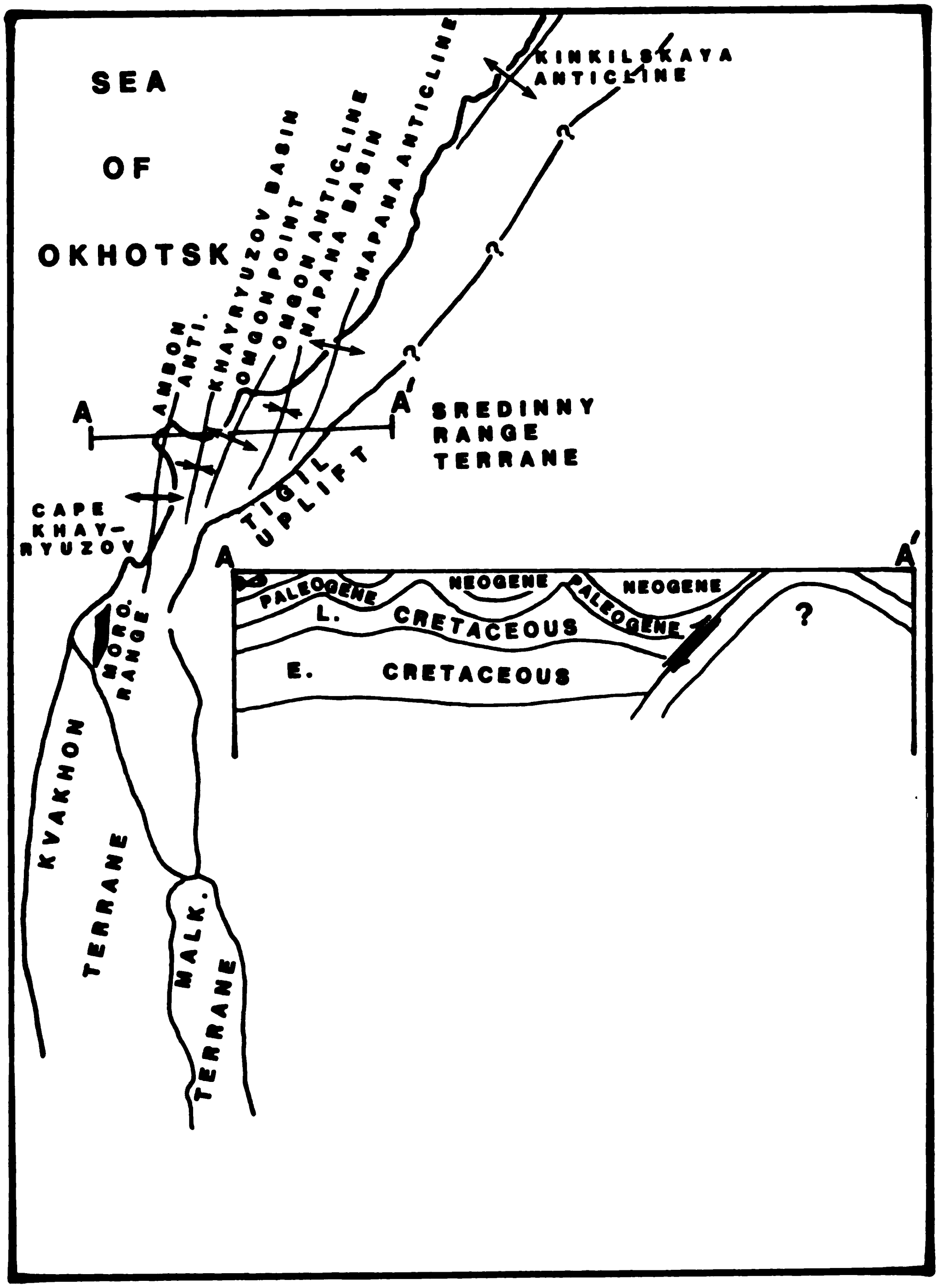
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Figure 12

the middle Cretaceous age of the overlying sediments.

Exposed in at least three localities of the Omgon terrane is an Albian to Santonian clastic sedimentary sequence that unconformably overlies the igneous basement rocks (Voronkov and Smirmov, 1971; Gnibidenko et al., 1974). Voronkov and Smirnov (1971) name the sequence the Omgon series and describe its exposures in two localities. In the Moroschechnyy Range, the Tal'niki suite, the lower suite of the Omgon series, consists predominantly of 1100 meters of shales with interbeds of siltstone and sandstone. The unconformably overlying Maynachskaya suite has a basal conglomerate and consists predominantly of 500 to 600 meters of sandstone with interbeds of siltstone and shale. The suite is late Turonian to Santonian in age. The beds of sandstone and shale are 150 to 200 meters thick and often contain pyroclastic material. Conglomerate units 0.5 to 4 meters thick are sporadically found in the sandstone units.

At Omgon Point, the series is nearly identical, with shales predominating in the Tal'niki suite and sandstones predominating in the Maynachskaya suite. One difference to note between the exposures of the series at the two localities, however, is the presence of somewhat more shale and siltstone throughout the section at Omgon Point as compared to the section exposed in the Moroschechnyy Range. In addition, the Omgon series is dated by findings of fragments of the middle and Late Cretaceous mollusk, Inoceramus.

Exposed in the isthmus of Kamchatka, west of the Kinkilskaya anticline zone, is the Lesnovo series, a Cenomanian to Turonian sandstone and shale sequence, 3000 meters thick, (Krasny, 1964; Shapiro, 1981) that is considered an eastern extension of the Omgon series (Avdeiko, 1971). The lower portion of the series and the base upon which it was deposited is not exposed. But basement material is suggested to consist of rocks similar to basement material exposed elsewhere in the Omgon terrane (Avdeiko, 1971).

Other references to middle Cretaceous clastic sequences in the Omgon terrane are Gnibidenko et al. (1974) who briefly mention an Albian to lower Senonian (Santonian?) terrigenous sequence exposed in the limbs of the Kinkilskaya anticline and Smirnov (1971) who mentions exposures of early Albian marine deposits found at Cape Khayryuzov. Unfortunately, neither reference gives further details, such as the method of dating of the rocks nor a more precise stratigraphic and compositional description. The general references do, however, demonstrate the widespread occurrence of Early to Middle Cretaceous clastic sequences throughout the Omgon terrane.

The Tertiary stratigraphy of the Omgon terrane is essentially identical to the contemporaneous deposits of the Kvakhon terrane in the terms of age, stratigraphic division and composition. Two differences, however, do exist. The Khulgun suite, the lowermost suite of the Tigil series not found in the Kvakhon terrane is exposed in the Tigil region of the Omgon terrane. The suite is Paleocene in age and unconformably overlies Cretaceous rocks. The suite consists of interlayered sandstones and conglomerates, with a conglomerate sequence at the base, and is up to 70 meters thick. The Early Eocene to Early Oligocene Napana and Snatol' suites of the Tigil series conformably overlie the Khulgun suite and consist of the same facies in both the Omgon and Kvakhon terranes. However, the middle and Late Oligocene rocks of the Omgon terrane differ in the southern and northern regions. In the southern region, the Kovacha series described in the Kvakhon terrane section is identical to the contemporaneous rocks of the Kvakhon terrane. However, in the northern part of the Omgon terrane, the middle and Late Oligocene rocks consist of the Cape Kinkilsky suite, made up of tuffs and greenish sandstones overlain by undifferentiated lavas and tuff breccias. The suite is up to 2500 meters thick and contains an Oligocene flora (Nalivkin, 1973; Krasny, 1964). The rest of the Tertiary section, from the Early Miocene through the Quaternary, is similar throughout the terrane and consists of coarse and fine clastics in addition to tuffaceous material. The series names are referenced as the Voyampol and Kavran series, the same as in the Kvakhon terrane. The sequences are generally thinner in the Omgon terrane but are essentially identical.

The Omgon terrane can be divided into several uplifts and basins (fig. 12) that trend in a general north/south direction. Cretaceous and Paleogene rocks are commonly exposed along the axes of the uplifts. The Moroschechnyy Range is a basement uplift bounded by faults and has middle Cretaceous strata exposed in its central portions. The Ambon anticlinorium is located at Ambon Cape and has Early Tertiary strata exposed in the core. The Omgon anticlinorium passes thru Omgon Point and has Cretaceous and Tertiary sequences exposed in the axis and limbs. Only middle Tertiary and younger strata are exposed in the center of the Napana anticline. To the west and east of the Omgon anticlinorium lies the Khayryuzov and Napana basins, respectively, that are filled in with thick Tertiary sedimentary column up to 3,000 meters thick (Smirnov, 1971). Along the west coast of the isthmus of Kamchatka lies the Kinkilskaya anticline, with Early Cretaceous volcanic rocks exposed in the core and Cretaceous sedimentary sequences exposed in the limbs.

As previously mentioned, the southern boundary of the Omgon terrane is the "Diagonal geosuture" across which lies the Kvakhon terrane. The suture is a zone of faults trending northwest/southeast. The eastern boundary of the terrane is the Tigil uplift or anticlinorium (fig. 6). Mafic and ultramafic volcanic rocks containing blueschist metamorphic mineral assemblages are exposed along the uplift (Sidorchuk and Khanchuk, 1981; Dobretsov and Kuroda, 1974) and are suggested to be associated with steep folds accompanied by thrust faulting described in the same area (Dmitriyeva, 1981; Aprelkov and Zhegalov, 1972; Volynets et al., 1965). This suture zone is a direct extension of the Kvakhon/Malkinsky suture zone located to the south (Sidorchuk and Khanchuk, 1981).

The continuation of the eastern boundary of the Omgon terrane north from the Tigil region cannot be determined precisely from the available data. The problem of the position of the boundary occurs due to a lack of data on the geology of the rocks exposed in the isthmus of Kamchatka. Tentatively, the boundary is suggested to extend approximately along the line that separates the middle Cretaceous clastic outcrops to the west from outcrops of Late Cretaceous oceanic crust to the east. The highly deformed and thrust faulted character of the Late Cretaceous rocks (Dmitriyeva, 1981; Aprelkov and Zhegalov, 1972) indicates that allochthonous layers of the oceanic sequence may have been thrust in sheets for several kilometers over the middle Cretaceous rocks located to the west. The boundary zone is thus based on stratigraphic age differences and the genetic origin of the rocks and not on the presence of a major fault or suture zone.

The general tectonic evolution of the Omgon terrane is as follows. Early Cretaceous arc activity is indicated by the presence of pyroclastic material in the Omgon series and by the Cretaceous diorite and granite found in the Moroschechnyy Range and at Omgon Point. In addition, the blueschist/thrust suture zone exposed in the Tigil uplift is indicative of a Cretaceous (Jurassic?) subduction zone and inferred island arc activity. The suture zone is a direct continuation of the Kvakhon/Malkinsky suture zone (Sidorchuk and Khanchuk, 1981) implying the arc facies of the Omgon terrane may be the northern extension of the Late Jurassic to Early Cretaceous Kvakhon arc.

The somewhat coarser clastics and the pyroclastic material of the Omgon series found in the Moroschechnyy Range as compared to the exposures of the Omgon series at Omgon Point suggest the Moroschechnyy Range area may have been located in closer proximity to the (active?) volcanic arc during Cretaceous time than Omgon Point. The cessation of arc activity is difficult to determine but most likely occurred sometime in the Early Cretaceous, as evidenced by the lack of abundant arc facies throughout the middle Cretaceous Omgon series.

A break in the deposition of the fine clastics of the Tal'niki suite occurred in Turonian time in response to a general uplift. The event led to the unconformity that separates the Tal'niki and Maynachskaya suites and to the eastward transgression and deposition of the Lesnovo series. The generally coarser clastics of the Maynachskaya suite were deposited after the hiatus through Santonian time.

A major unconformity from Campanian to Danian time, approximately 20 Ma., separates the Cretaceous and Tertiary sedimentary sequences. Deposition recommenced in Early Tertiary time with the Tigil series, a sequence of shallow marine and continental facies. The Khulgun suite, where exposed, consists predominantly of conglomerates, indicative of the onset of sedimentation.

The Tertiary strata are generally devoid of volcanic material in the southern part of the Omgon terrane, except for small amounts of Miocene and Pliocene tuffs and Quaternary volcanics. In the northern part of the terrane, clastic sedimentation occurred through Paleocene to Early Oligocene time but middle and Late Oligocene rocks are dominated by a sequence of undifferentiated volcanic material. The period of volcanic activity had ceased by Early Miocene time and was followed by a period of Miocene to Quaternary sedimentation that also contains sporadic volcanic material similar to what is found in the southern part of the terrane. Uplift of the Tigil anticlinorium occurred during Middle Miocene time while subsidence of the Napana basin occurred in the Late Oligocene to Early Miocene time.

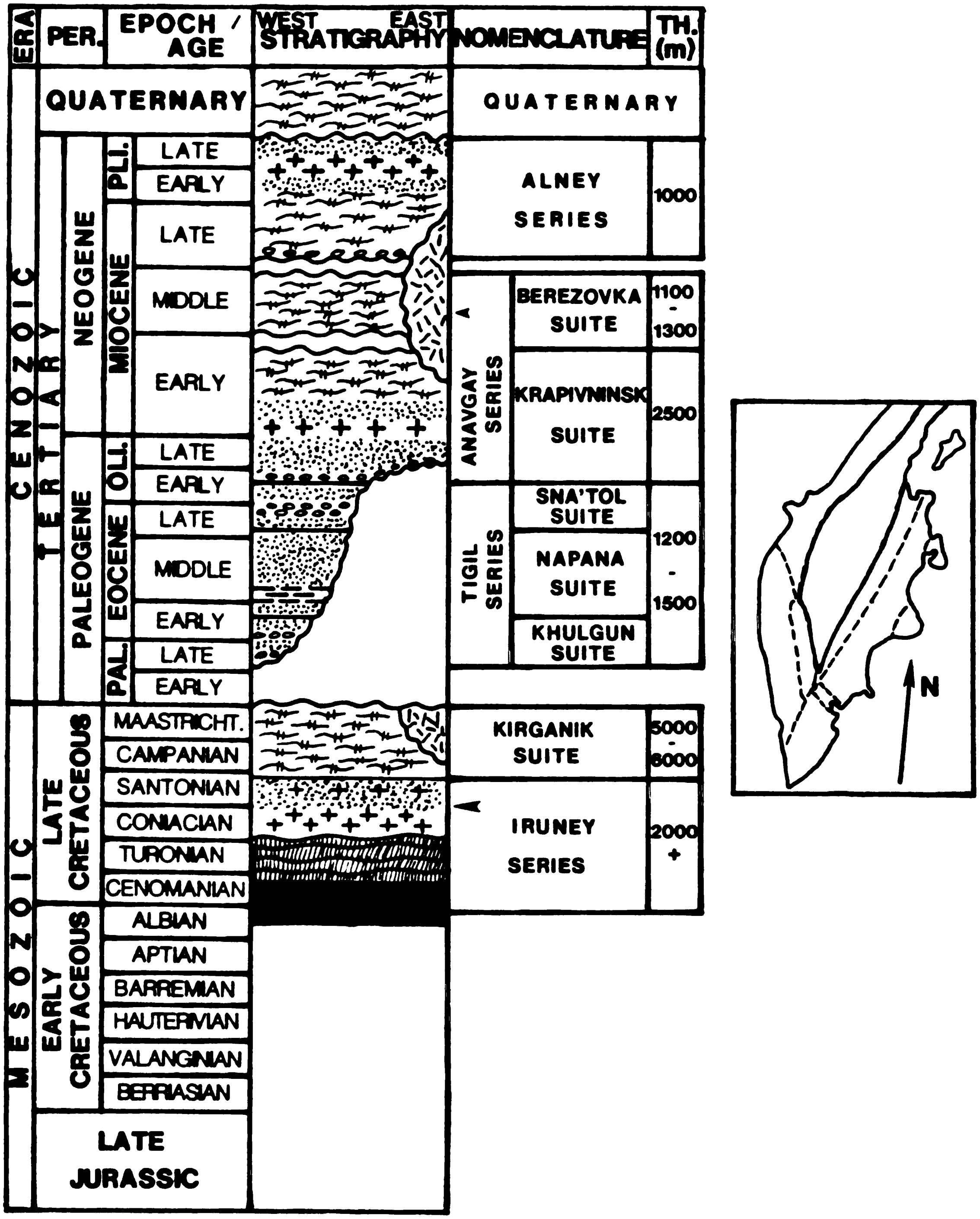
SREDINNY RANGE TERRANE

The Sredinny Range terrane is located in central and northern Kamchatka (fig. 6) east of the Omgon terrane and west of the Central Kamchatka Basin. Generally, the stratigraphy of the terrane includes the facies of two island arc systems with basement rocks consisting of oceanic crust (fig. 13). Extensive Neogene and Quaternary volcanic cover obscures older formations, particularly in the eastern and central regions of the terrane.

The basement of the terrane is the Iruney series, an oceanic layer as indicated by abundant spilitic pillow basalts, tuffs, jaspers, cherts, radiolarians and rare limestone (Shapiro, 1981; Belyy, 1974). The series is several kilometers thick and is exposed in the northern, western and southern regions of the terrane but not in the eastern and central regions. Occurrences of diabase, gabbro, peridotite, pyroxenite and wehrlite amongst the basalts are common (Gnibidenko et al., 1974; Belyy, 1974). The Iruney series is equivalent to the "siliceous-volcanogenous formation" commonly referred to in the Soviet literature.

Conformably overlying the Iruney series is the Kirganik suite of Campanian to Maastrichtian age. It consists of coarse andesite and andesite-basalt volcanics with layers of tuffs, tuffaceous sediments and chert and is up to 5000 to 6000 meters thick (Shapiro, 1981; Markov and Khotin, 1973). Exposures of the suite are found in the southern

Figure 13 - Stratigraphy of the Sredinny Range terrane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LATE
EARLY
ALNEY SERIES
1000
ANAVGAY SERIES
BEREZOVKA SUITE
1100 - 1300
KRAPIVNINSK SUITE
2500
TIGIL SERIES
SNA'TOL SUITE
NAPANA SUITE
1200 - 1500
KHULGUN SUITE
MESOZOIC
LATE CRETACEOUS
MAASTRICHT.
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
KIRGANIK SUITE
5000 - 6000
IRUNEY SERIES
2000 +
EARLY CRETACEOUS
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
LATE JURASSIC
N

Figure 13

and northern parts of the terrane while exposures of the suite in the central regions of the terrane are suggested to be obscured, as with the Iruney series, due to abundant Neogene volcanic and clastic cover.

The Iruney series and Kirganik suites are commonly thrust faulted and highly deformed (Aprelkov and Zhegalov, 1972; Krasny, 1964). In the southern region of the terrane, the rocks are considered allochthonous (Zhegalova, 1981) and are thrusted over the western margin of the autochthonous Malkinsk block. Dunites, peridotites, serpentinites and gabbros are exposed along the thrust plane (Krasny, 1964). In the northern parts of the terrane, the sequences are cut by numerous faults and are steeply folded (Aprelkov and Zhegalov, 1972). In addition, metamorphism up to the greenschist facies level has occurred in response to the deformation of the rocks and to the intrusion of Late Cretaceous, Early Tertiary and Miocene granitic and gabbroic plutons (Dobretsov, 1975).

The Tertiary stratigraphy of the western portion of the terrane differs from the stratigraphy of the remainder of the terrane. Found along the Tigil uplift, in the western part of the terrane, is the Paleocene to Early Oligocene Tigil series made up of essentially identical facies as described for the series in the Omgon terrane (Dmitriyeva, 1981). The middle and Late Oligocene Kovacha series overlies the Tigil series and is also equivalent to contemporaneous formations found in the Omgon terrane. The

Early to Late Miocene section of the region, the Voyampol series, unconformably overlies the older rocks and consists of interlayered tuffaceous sandstones and tuffs with calcareous horizons generally containing more pyroclastic material (tuffs), than the contemporaneous rocks of the Omgon terrane. Completing the Neogene section in the western region is the Late Miocene to Pliocene Kavran series, made up of the Il'insk and Kakert suites consisting of siltstones and tuffaceous sediments and the Etolon and Erman suites consisting of sandstones, siltstones and tuffaceous horizons. The Quaternary section consists of plateau basalts and pyroclastics.

In the northern, central and southern regions of the terrane, the Late Oligocene to Middle Miocene Anavgay series unconformably overlies the Cretaceous rocks. The Krapivninsk suite, the lower suite of the series, is 2500 meters thick and of Late Oligocene to Early Miocene age. The base of the suite consists of alternating conglomerate, sandstone and tuff that gradually change up the section into andesite-basalt, andesite and tuff breccias with layers of tuffite and tuffaceous sandstone (Rotman, 1960; Shantser et al., 1965). The Berezovka suite, the upper suite of the series, unconformably overlies the Krapivninsk suite and is Middle Miocene in age. The suite consists predominantly of tuff-breccias, tuffites, andesites and dacites and ranges in thickness from 1100 to 1300 meters.

Both suites of the Anavgay series are dated by abundant floral and faunal remains (Shantser et al., 1965).

Unconformably overlying the Anavgay series in the Alney series, Late Miocene to Late Pliocene in age, that consists of andesite-basalt, andesite, tuff-breccia and tuffs with layers of fine to coarse grained clastic sediments. The series is 1000 meters thick and has a basal conglomerate. Completing the section of this region of the terrane are abundant Quaternary basalt and andesite-basalt flows, ranging in thickness from 500 to 1000 meters.

Many different lithological types of intrusives are found in the Sredinny Range terrane. Late Cretaceous to Early Tertiary intrusives consist of gabbros, diorites and granites that intrude Late Cretaceous sequences (Dmitriyeva, 1981; Krasny, 1964; Volynets et al., 1965). These intrusives are found mostly in the northern portions of the terrane. More extensively developed along the entire length of the terrane are gabbro, diorite, granodiorite and granite intrusives of Miocene age. Erlich (1979) reports ten K-Ar radiometric age dates form the granitoids of the Sredinny Range that have an average age of 16 Ma (late - Early Miocene).

The Palana Basin is a major structural feature located along the western margin of the Sredinny Range Terrane, just east of the Tigil uplift (Dmitriyeva, 1981; Gnibidenko et al., 1974). Exposed in the basin are Late Eocene through Quaternary sediments and volcanics, with the

Miocene section being the thickest. Seismic data indicate the thickness of the Tertiary deposits ranges from 1200 to 1500 meters, but sometimes reaches up to 3000 meters (Dmitriyeva, 1981). The rocks of the basin are only slightly tilted, 5 to 10 degrees, and are rarely folded (Dmitriyeva, 1981).

The Sredinny Range terrane is bounded on the west by the Tigil uplift and the tentative continuation of the uplift to the north described in the Omgon terrane section. The southwestern margin of the terrane is a thrust faulted region where the oceanic crust of the Iruney series and the overlying calc-alkaline volcanics of the Kirganik suite are thrust in one, or several, sheets over the Malkinsk block (Zhegalova, 1981). In this case the Iruney series and the Kirganik suite are allochthonous. Located along the eastern margin of the terrane is the Central Kamchatka Basin (fig. 6). A geophysically identified, elongate and narrow trough found along the western margin of the basin is suggested to be related to the subduction zone and trench system associated with the eruption of the Late Cretaceous and Early Tertiary island arc facies of the Kirganik suite (Rivosh, 1964).

The tectonic evolution of the Sredinny Range terrane commenced in Santonian to Companian time with the development of the calc-alkaline volcanics of the Kirganik suite. The suite was deposited onto the Iruney series, a pre-Santonian oceanic layer. Together, the Iruney series and the Kirganik suite are referred to as the Iruney arc (Belyy, 1974). The period of activity of the arc lasted through Maastrichtian, possibly Danian, time. The trench and subduction zone of the arc were located to the east, at the present site of the trough identified by gravity and magnetic anomaly lows found along the western margin of the Central Kamchatka Basin. Thrust faulting and deformation of the Cretaceous rocks occurred in latest Cretaceous or earliest Tertiary time in response to accretion of the terranes of eastern Kamchatka to the Iruney arc and the terranes of western Kamchatka.

Deposition of clastic sequences commenced in Paleocene time with initial subsidence of the Palana Basin occurring in Late Eocene time. In Late Oligocene to Early Miocene time, arc activity of the middle Tertiary Sredinny Range arc commenced. Contemporaneously, subsidence of the Palana Basin continued but at an increased rate (Smirnov, 1971). The trench and subduction zone associated with the arc were located at the site of the Eastern Kamchatka Basin (fig. 25). The factors determining the tectonic relations between the two areas are given in the section on the geology of the Eastern Kamchatka Basin.

The rocks of the Sredinny Range arc are located along the entire length of the terrane. The Palana Basin, located westward of the arc, is considered to be a back arc basin that filled in with clastic and pyroclastic material from the active volcanic arc. The period of activity had ceased by Late Miocene or Pliocene time although sporadic volcanism continued to occur. Plateau basalt flows of Quaternary age conclude the tectonic sequence.

MALKINSK TERRANE

The most controversial area of Kamchatka is the Malkinsk block, sometimes referred to in the literature as the Central Massif. The problem arises because of the inconclusive and contradictory radiometric and paleontologic age data used to date the rocks of the terrane, estimates of which range from Precambrian to Late Cretaceous. The rocks in question generally consist of felsic igneous intrusives and metamorphosed sedimentary and igneous rocks (fig. 14). The complex tectonics of the terrane and the high metamorphic grade of the rocks adds uncertainty to the interpretation of the geological data.

The exposed basement of the terrane is the Kolpakova series, a high grade metamorphic unit consisting of migmatite, gneiss, crystalline schists and phyllites, the parents rocks of which were a pelitic unit (Gnibidenko et al., 1974; Lebedev et al., 1967; Krasny, 1964). Plagioclase rich granitic plutons found in the series are also metamorphosed. Overlying the Kolpakova series is the Malkinsk series, a moderate grade metamorphic unit containing three suites. The lowest suite, the Shikhtinsk suite, consists of schist, gneiss and meta-pelite and has a basal arkose conglomerate layer containing clasts of the underlying metamorphosed granite and gneiss of the Kolpakova series (Shul'diner et al., 1980; Shul'diner et al., 1979). The Andrianovka suite overlies the Shikhtinsk suite, and in some places, the Kolpakova series, and

Figure 14 - Stratigraphy of the Malkinsk terrane

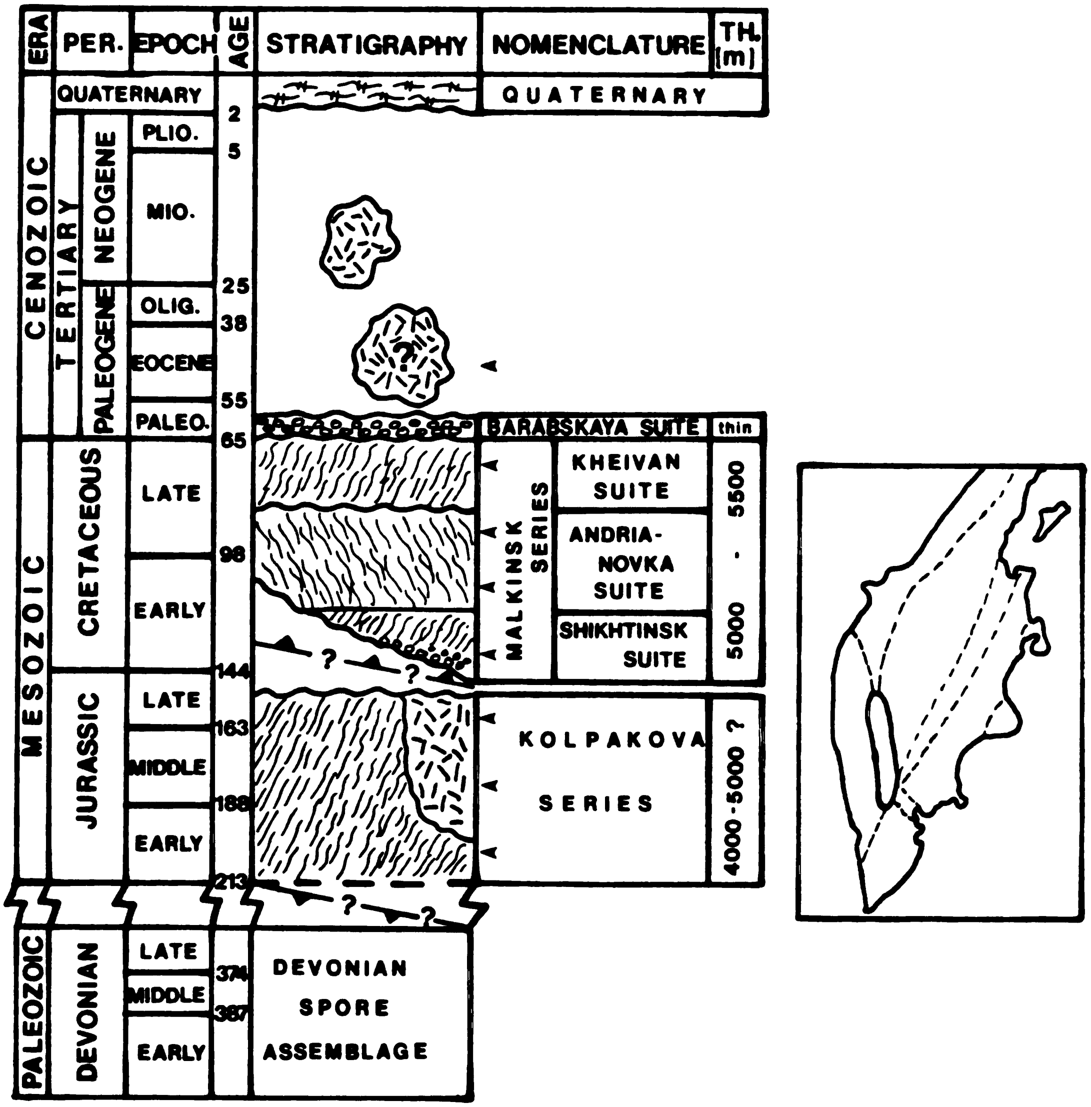
ERA
PER.
EPOCH
AGE
STRATIGRAPHY
NOMENCLATURE
TH. [m]
QUATERNARY
QUATERNARY
CENOZOIC
TERTIARY
NEOGENE
PALEOGENE
PLIO.
MIO.
OLIG.
EOCENE
PALEO.
2
5
25
38
55
65
BARABSKAYA SUITE
thin
MESOZOIC
CRETACEOUS
LATE
EARLY
98
144
MALKINSK SERIES
KHEIVAN SUITE
ANDRIA-NOVKA SUITE
SHIKHTINSK SUITE
5000 - 5500
JURASSIC
LATE
MIDDLE
EARLY
163
188
213
KOLPAKOVA SERIES
4000-5000 ?
PALEOZOIC
DEVONIAN
LATE
MIDDLE
EARLY
374
387
DEVONIAN SPORE ASSEMBLAGE

Figure 14

consists of greenschists with interbeds of coarse clastics and tuffs (Gnibidenko et al., 1974; Shul'diner et al., 1980). The volcanic rocks of the suite are at least partially of intermediate composition (Krasny, 1964). The suite has a basal tuff conglomerate layer exposed where it directly overlies the Kolpakova series. The Shikhtinsk and Andrianovka suites, and sometimes the Shikhtinsk suite alone, are referred to as the Kamchatka series (Mokrousov and Marchenko, 1964). The uppermost suite of the Malkinsk series, the Kheivan suite, consists of micaceous sandstones, phyllites and schists. The entire Malkinsk series is 5000 to 5500 meters thick. Late Mesozoic to Tertiary granites that intrude the series also intrude the Kolpakova series and are not metamorphosed (Shul'diner et al., 1980). The nature of the contact between the Kolpakova and Malkinsk series is uncertain but is either described as a thrust contact (Zhegalova, 1981) or an unconformity (Shul'diner et al., 1980).

Tertiary sequences of the Malkinsk terrane consist of isolated outcrops of the Barabskaya suite which contains a Paleocene flora (Shtempel, 1957), and limited Quaternary basalts and andesite volcanics and clastics. Several Soviet authors (e.g., Gnibidenko et al., 1974; Zhegalova, 1981) include the Kvakhon and Kikhchik series of the Kvakhon terrane and the Iruney and Kirganik series of the Sredinny Range terrane in the stratigraphic column of the Malkinsk terrane. Because these series are in tectonic contact with the Malkinsk terrane and consist of different lithofacies than the Kolpakova series, they are inferred to be associated with their respective, separate terranes.

The metamorphic characteristics of the Kolpakova and Malkinsk series differ considerably. The Kolpakova series has undergone two phases of metamorphism. Mineral assemblages that originated during the first phase increase in grade moving west to east across the northern exposure of the Kolpakova series, the area of the Khangar gneiss dome (Shul'diner et al., 1980). The lowest grade assemblage contains the minerals garnet, kyanite, biotite, muscovite, plagioclase, potassium feldspar and quartz. To the east lies assemblages consisting of garnet, kyanite, biotite, plagioclase, potassium feldspar, quartz and cordierite. Some of the K-spar is orthoclase. Another assemblage consists of garnet, hypersthene, biotite, plagioclase, potassium feldspar and quartz. These mineral assemblages developed under high pressure and temperature conditions of at least 6 to 8 kilobars of pressure and 600 to 750 degrees celsius and are indicative of amphibolite grade metamorphism and possibly, granulite facies, metamorphism (Shul'diner et al., 1980). In addition, the event was not a contact metamorphic event because of the increase in the metamorphic grade moving west to east over a distance of several kilometers. This event, therefore, most likely was a regional metamorphic event.

The second metamorphic event occurred under different, lower grade conditions such that mineral assemblages of the first event are altered to lower grade assemblages (Shul'diner et al., 1980). Garnet is replaced by fine grained biotite and muscovite. Kyanite is replaced by muscovite and andalusite. Primary biotite is replaced by muscovite and chlorite while cordierite is replaced by spinel, muscovite, andalusite or sillimanite. The secondary muscovite extends through the exposures of the gneiss dome (Kolpakova series) while andalusite occurs along the periphery and sillimanite occurs towards the central regions of the dome. The abundance of andalusite from the secondary metamorphism indicate an event of low pressure (Shul'diner et al., 1980).

In contrast to the poly-metamorphic character of the Kolpakova series, the Malkinsk series was metamorphosed only once. The characteristics of the Malkinsk metamorphism are similar to the second event of the Kolpakova series (Shul'diner et al., 1980). Characteristic mineral assemblages found in the Shikhtinsk suite, the metamorphic grade of which increases towards the base of the suite, include garnet, staurolite, biotite, muscovite, chlorite, plagioclase and quartz found away from the contact with the underlying Kolpakova series, and garnet, sillimanite, biotite, muscovite, plagioclase and quartz found near the contact (Shul'diner et al., 1980). Mineral assemblages of the Andrianovka suite include chlorite, actinolite and albite, and of the Kheivan suite, biotite, garnet, staurolite and andalusite (Gnibidenko et al., 1974). The mineral assemblages of the Malkinsk series developed under moderate conditions of 2 to 4 kilobars pressure and temperature of 450° to 600° celsius and are indicative of greenschist facies metamorphism (Shul'diner et al., 1980). In addition, the event occurred under conditions of a high geothermal gradient and is most likely the result of a regional metamorphic event. Generally, the metamorphic rocks of the Malkinsk terrane consist of the amphibolite, possibly granulite, facies rocks of the Kolpakova series surrounded by the greenschist facies rocks of the Malkinsk series, the metamorphic grade of which slightly increases moving toward the Kolpakova/Malkinsk series' contact.

Paleontological dates from the Malkinsk terrane are sparse and some may be questionable. The only dates considered potentially reliable are indicated by the finds of a Devonian and Carboniferous spore assemblage that is considered very representative of spore complexes of that age (A. Cross, pers. comm.). The assemblage is reported to have been found in a biotite schist and a dark shale, both from the Kheivan suite of the Malkinsk series (Sivertseva and Smirnova, 1974). The report of a similar assemblage from both metamorphosed and un-metamorphosed rocks lends uncertainty to the validity of the finds since spores are generally destroyed during metamorphic events over 150 degrees celsius (Tschudy, 1969). However, spores are very durable in terms of weathering and reworking of older rocks. The possibility therefore exists that the spores may have been transported from the dark shale into microfractures in the schist after the metamorphic event occurred or from other blocks of Paleozoic age that are present in the Central Massif. Aksenovich et al. (1964) has described finds of Devonian, Carboniferous, Triassic and Jurassic spores and Triassic flora from the Kikchik series of the Kvakhon terrane, all of which are poorly preserved. These data are confusing, conflicting and tend to question the validity of any Paleozoic floral or faunal remains in the Malkinsk series or Kamchatka. If Paleozoic rocks are present, it is possible that blocks of Paleozoic rocks exist or once existed in the Malkinsk terrane but lack of geologic data on the area precludes this determination.

Radiometric age dates from the metamorphic rocks of the terrane are numerous, but, their variety obscures a determination of the age of the original rocks of the terrane. Several dates from the metamorphic basement of the terrane, either the Kolpakova or the Malkinsk series have been obtained using the K-Ar isotopic method (Erlich, 1979; Kuz'min and Chukonin, 1980) (fig. 15). The ages range from 314 to 15 Ma with three dates in the range from 103 to 90 Ma and with six dates in the range from 64 to 46 Ma. Three U-Pb dates averaging 1.36GA (Precambrian) have been obtained from a biotite gneiss of the Kolpakova series (Kuz'min and Chukonin, 1980). However, since only a few

Figure 15 - Potassium - argon radiometric dates from Kamchatka Peninsula

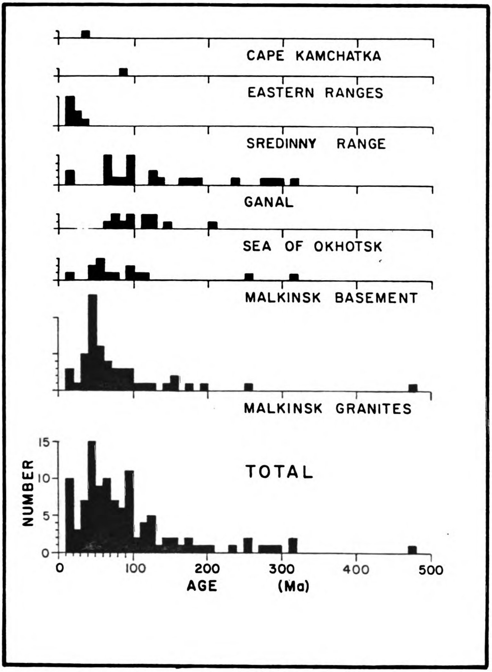
CAPE KAMCHATKA
EASTERN RANGES
SREDINNY RANGE
GANAL
SEA OF OKHOTSK
MALKINSK BASEMENT
MALKINSK GRANITES
TOTAL
NUMBER
0
5
10
15
0
100
200
300
400
500
AGE (Ma)

Figure 15

milligrams of zircon were available for testing, a method of measuring Pb 207/Pb 206 ratios through thermionic emission (Chukonin, 1978) was used. The method and consequently, the results, are considered questionable due to the unconfirmed method of isotopic measurement in conjunction with the small amount of zircon used in the study. Kuzmin and Chukonin (1980) also provide several K-Ar radiometric age dates from the Kolpakova series and indicate the rock type or mineral that was tested (table 2). Utilizing the data of Hyndman (1972, pg. 328) indicating which minerals best retain the radioactive decay daughter isotope, argon, during metamorphism, a plot is obtained (fig. 16) that reveals an upper age limit of 78 Ma for the metamorphic event. In summary, the metamorphism of the Kolpokova series occurred around or before 78 Ma (Campanian) indicating an older age for the deposition of the parent rocks of the series. No radiometric data are available on the Malkinsk series.

Intrusions into the Malkinsk terrane consist predominantly of granite and granodiorite of Mesozoic and Cenozoic age. Granite intruding only the Kolpakova series are metamorphosed but those intruding both the Kolpakova and Malkinsk series are not. Ages of the granites are determined by the K-Ar isotopic method and range from 192 to 30 Ma, with 70% of the dates clustering in the period from 50 to 40 Ma (Gnibidenko et al., 1974).

The characteristics of the boundaries of the Malkinsk terrane with the Kvakhon and Sredinny Range terranes has

Table 2 - Potassium - argon radiometric dates from the Kolpakova series of the Malkinsk terrane

Table 2

ROCK TYPE	NO. OF DETERMINATIONS	AVERAGE AGE (Ma)
gneiss	8	78
gneissoid granite	5	85
biotite - from a gneissoid granite	2	53
plagiogranite	12	57
biotite - from a plagiogranite	4	47
biotite	3	44
muscovite - from a pegmatite	3	53
feldspar - from a pegmatite	3	45
biotite - from a biotite gneiss	1	41
plagioclase - from a biotite gneiss	1	74

Figure 16 - Age estimate of metamorphism of the Malkinsk terrane based on argon retention potential of various minerals

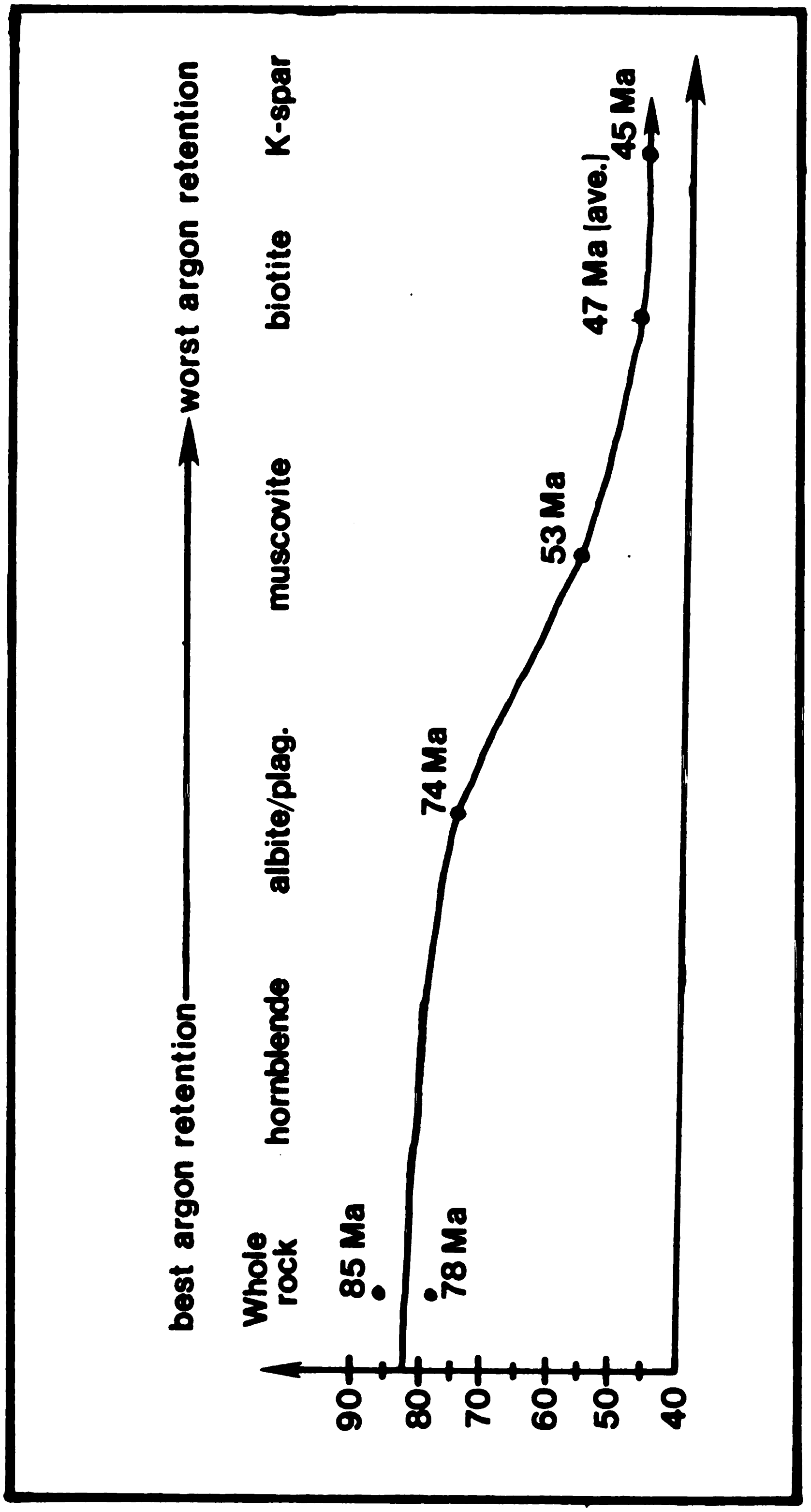
best argon retention
worst argon retention
Whole rock
hornblende
albite/plag.
muscovite
biotite
K-spar
85 Ma
78 Ma
74 Ma
53 Ma
47 Ma (ave.)
45 Ma
90
80
70
60
50
40

Figure 16

already been described in preceding sections. The southeastern boundary of the Malkinsk terrane is the normal faulted, narrow graben of the southern portion of the Central Kamchatka basin. This boundary also extends along the entire eastern margin of the Sredinny Range terrane.

The tectonic evolution of the Malkinsk terrane is as follows. Deposition of the pelitic rocks that were the parent rocks of the Kolpakova series occurred in late Paleozoic or early Mesozoic time, possibly on oceanic crust. This age is based on the Early Jurassic radiometric age dates from granites of the terrane that indicate an upper age for their formation, and consequently, for the deposition of the parent rocks of the Kolpakova series. High grade metamorphism throughout Jurassic time related to subduction zone activity transformed the pelitic unit into the amphibolite grade crystalline schists and gneisses of the Kolpakova series. This metamorphic activity was probably accompanied by the intrusion of granitic and granodioritic plutons that were subsequently deformed by continued tectonic activity. Post-orogenic emplacement of the plutons probably also occurred. The origin of the volcanics of the Andrianovka suite and the clastics of the Kheivan suite is uncertain. Possibly, the Andrianovka suite was deposited (erupted) during the period of subduction that metamorphosed the Kolpakova series. Subsequent subsidence of the block led to the deposition of the Kheivan suite. A later period of uplift, erosion and metamorphism, possibly due to an accretionary event, exposed the metamorphic core of the Kolpakova series and removed all but the outer margins of the Malkinsk series. An alternate, although still tenuous, hypothesis is the Andrianovka and Kheivan suites are allochthonous sheets that developed separately from the Kolpakova series but were thrust over and obducted onto the series in Jurassic or Cretaceous time. The metamorphism of the series, and the second period of metamorphism of the Kolpakova series, would result from the dynamothermal processes of the accretionary obduction event. Development of Late Cretaceous and Tertiary granitic plutons in response to the nearby volcanic are activity of the Late Cretaceous Iruney arc and the Neogene Sredinny Range arc may also have metamorphosed to a certain extent the Kolpakova and Malkinsk series. At any rate, the obduction hypothesis would explain the metamorphic grade differences between the Kolpakova and Malkinsk series, the increase in grade of metamorphism towards the Kolpakova/Malkinsk contact, i.e., at the base of the Shikhtinsk suite, and the rubble found at the base of the Malkinsk series.

Obduction of the Kvakhon terrane onto the Malkinsk terrane is suggested to have occurred by 97 Ma (Cenomanian), one of the clustering ages of radiometric dates from the Kolpakova series. Other evidence favoring a period of uplift in western Kamchatka at this time is the late Cenomanian to Turonian unconformity separating the

Tal'niki and Maynachskaya suites of the Omgon series of the Omgon terrane and the thick clastic section of the Lesnovo series found in the eastern and northern regions of the Omgon terrane. Gnibidenko et al. (1974) has pointed out stratigraphic similarities between the Kvakhon and Kikchik series of the Kvakhon terrane and the Andrianovka and Kheivan suites and suggests the two units are the same, except that a regional metamorphic event altered the Malkinsk series. It is possible then that the Malkinsk series is an allochthonous thrust sheet of the Cretaceous rocks of the Kvakhon terrane. Lack of paleontological remains in the Malkinsk series that are described in the Cretaceous rocks of the Kvakhon terrane does not support this idea although the metamorphic grade of the Malkinsk series may explain their obscurity.

The clustering around 40 to 50 Ma of radiometric age dates from both the metamorphic rocks and the granitic plutons corresponds to a major Early Tertiary accretionary and consolidation episode, including the thrusting of the Iruney arc over the eastern margin of the Malkinsk terrane. It is suggested that the metamorphic conditions induced by a thermal disturbance during this time released argon from the granitic and metamorphic rocks of the terrane. The K-Ar dates consequently reflect the date of the accretionary event.

Neogene and Quaternary igneous activity led to the development of Miocene granites and Quaternary volcanics and clastics.

The Eifelian (Middle Devonian) age of spores in the Khievan suite reported by Sivertseva and Smirnova (1974) is identical to that of fauna found in sediments overlying the Ust-Belaya ophiolite complex found to the north of Kamchatka in the Koryak Highlands (Fujita and Newberry, 1983). In addition, Devonian rocks are also found in a Mesozoic subduction complex in southwestern Japan that are suggested to have been emplaced during a period of transcurrent motion or oblique subduction in Mesozoic time (Taira et al., 1983). The possibility therefore exists that fragments of Devonian aged blocks have been rafted northward along the Mesozoic Asiatic margin in a manner similar to what has been observed in certain western North American terranes, such as Wrangellia (Jones et al., 1977), leading to the emplacement of the Paleozoic rocks along the Japanese and Northeast Siberian coasts.

CENTRAL KAMCHATKA BASIN

The Central Kamchatka Basin is bounded by the Eastern Ranges and Karaginsky Island on the east and by the Sredinny Range and Malkinsk terranes on the west (fig. 6). The basin extends from the Ganal Range in the south, north through Litke Strait and into the Koryak Highlands. The width of the basin is approximately 60 kilometers from its northernmost extent to the central region and from there, south to the Ganal Range, the basin narrows to a thin graben, varying in width from two to eight kilometers. Generally, the basin is underlain by oceanic crust overlain by Oligocene, possibly Paleocene and Eocene, and younger volcanics and clastics (fig. 17). Extensive Quaternary volcanic and clastic cover obscures the older formations.

Evidence for an oceanic layer underlying the terrane is as follows. The Khavyven Uplift is located southwest of Ozernoy Peninsula and is suggested to represent an outcrop of metamorphosed basement rocks (Gnibidenko and Marakhanov, 1973). The rocks consist of greenschists and microquartzites, 1000 to 1500 meters thick, containing mafic and ultramafic intrusives (Gnibidenko and Marakhanov, 1973; Shul'diner et al., 1979). Characteristic minerals include chlorite, epidote, actinolite, albite, quartz, biotite, muscovite and tremolite and are indicative of epidote-amphibolite facies metamorphism. Garnet is also present but rare. The parent material of the complex was a mafic volcanic and sedimentary complex, indicated by the

Figure 17 - Stratigraphy of the Central Kamchatka Basin terrane

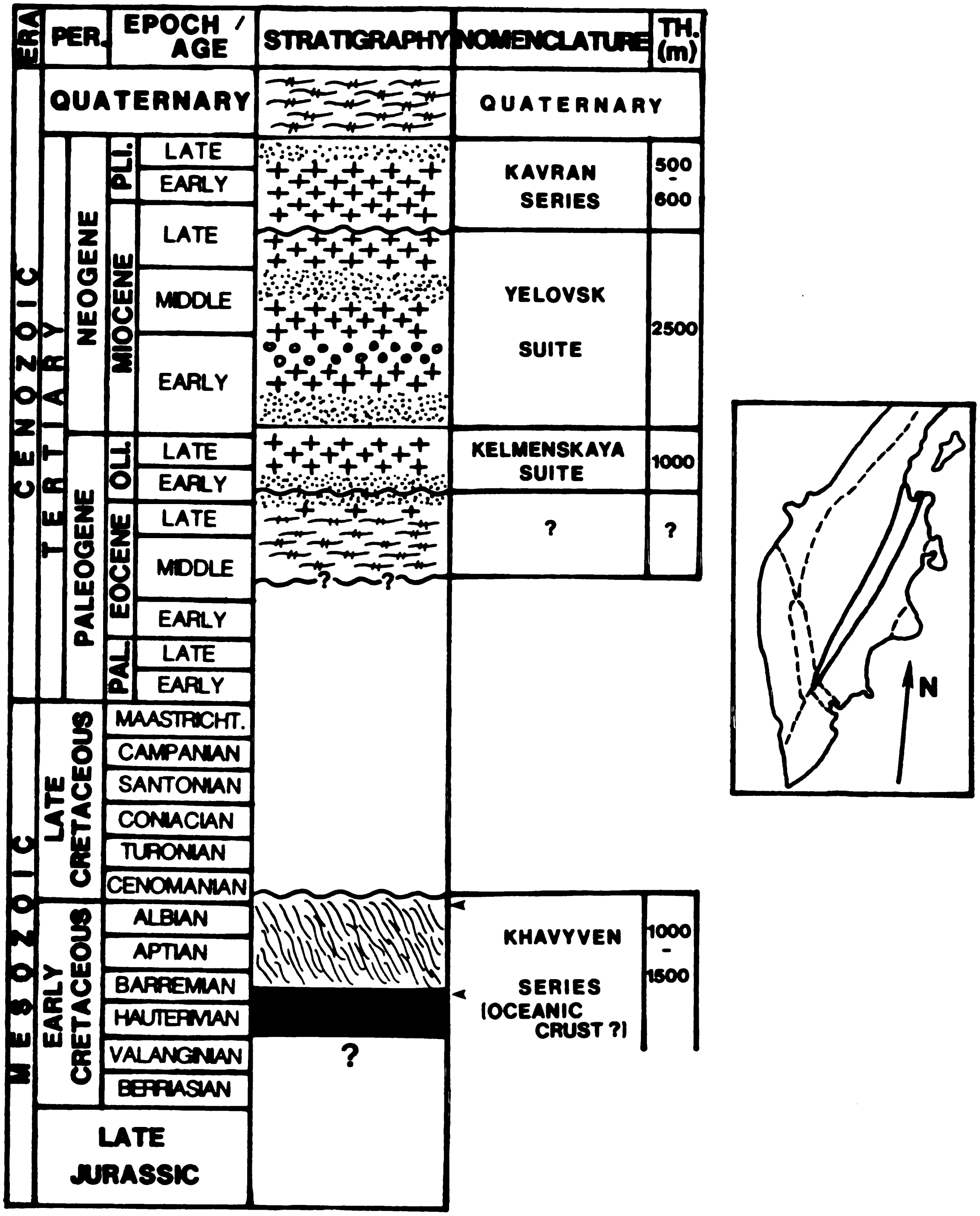
ERA
PER.
EPOCH / AGE
STRATIGRAPHY
NOMENCLATURE
TH. (m)
QUATERNARY
QUATERNARY
CENOZOIC
TERTIARY
NEOGENE
PLI.
LATE
EARLY
KAVRAN SERIES
500 - 600
MIOCENE
LATE
MIDDLE
EARLY
YELOVSK SUITE
2500
PALEOGENE
OLI.
LATE
EARLY
KELMENSKAYA SUITE
1000
EOCENE
LATE
MIDDLE
EARLY
?
?
PAL.
LATE
EARLY
MESOZOIC
LATE CRETACEOUS
MAASTRICHT.
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
EARLY CRETACEOUS
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
KHAVYVEN SERIES (OCEANIC CRUST ?)
1000 - 1500
?
LATE JURASSIC
N

Figure 17

composition of the metamorphic rocks. K-Ar radiometric age dates ranging from 122 to 92 Ma have been obtained and most likely indicate a metamorphic event (Gnibidenko and Marakhanov, 1973).

Seismic velocities of 5.7 to 6.5 km/sec from a refracting boundary lying at depths of 3 to 7 kilometers determined in a refraction profile across the central region of the basin are indicative of an oceanic layer (Utnasin et al., 1975). On the basis of high gravity (Δ g) and magnetic anomalies (Δ Ta) trending along the eastern half of the basin, Rivosh (1964) concluded that dense material (e.g., mafic effusives) lies at depths of 1.5 to 2 kilometers in the basin. The magnitude of the anomalies decrease (fig. 18) corresponding to a general increase in depth to basement in the same direction (Rivosh, 1964). Low magnitude anomalies extend along the entire western margin of the basin as a narrow band and indicates the position of an elongate and narrow, sediment filled, trough (Rivosh, 1964). The oceanic crust of the basement, therefore, lies at shallow depths in the eastern and central parts of the basin and at greater depths along the eastern margin of the Sredinny Range terrane.

The sequences filling the basin are 2000 to 5000 meters thick and are of Oligocene to Quaternary age. The Paleogene and Neogene rocks are exposed only in the northern part of the basin, west of Ozernoy Peninsula. These formations, and/or other Paleogene or Cretaceous

Figure 18 - Magnetic anomaly map of Kamchatka Peninsula
(after Gnibidenko et al., 1974)

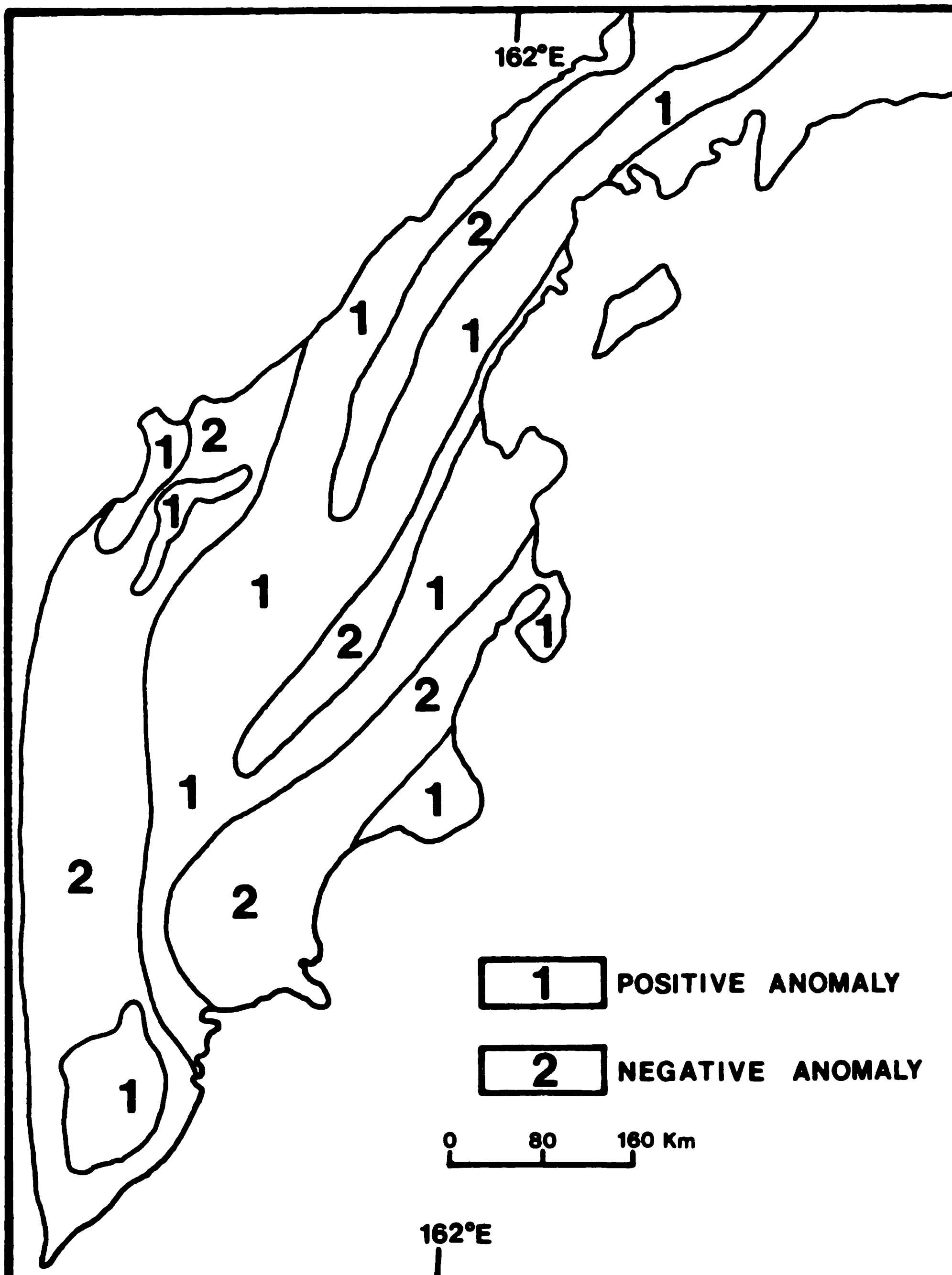
162°E
1
2
1
1
2
1
1
1
1
2
1
2
1
1
2
2
1
1
POSITIVE ANOMALY
2
NEGATIVE ANOMALY
0 80 160 Km
162°E

Figure 18

sequences are obscured by Quaternary cover in the remainder of the basin.

The lowermost suite overlying the basement is unnamed and consists of andesites, basalts, tuffs, tuffaceous sandstones and conglomerates. There are no age data on this sequence. Overlying the unnamed suite is the Kelmenskaya suite consisting of 1000 meters of interbedded tuffaceous sandstones and siltstones. Paleontologic data indicate a tentative Oligocene age (Mironoba, 1982). The Yelovsk suite, conformably overlying the Kelmenskaya suite, is Miocene in age and consists of 2500 meters of tuffaceous sandstones, siltstone and argillites with interbedded conglomerates. The unconformably overlying Kavran series of Late Miocene to Pliocene age consists of 500 to 600 meters of tuffs and tuffaceous sandstones. Quaternary andesites, basalts and their associated pyroclastics in addition to clastic deposits complete the section of the Central Kamchatka Basin.

The western boundary of the terrane, across which lie the Sredinny Range and Malkinsk terranes, is the geophysically identified, elongate and narrow trough often accompanied by normal faulting. The eastern margin of the terrane, across which lies the Eastern Ranges, Ganal and Southern Kamchatka terranes (fig. 6), is a zone of thrust and/or normal faults. The boundary separates the uplifted Eastern Ranges from the downdropped Central Kamchatka Basin. Seismic refraction data indicate the basement of the basin is downdropped 1500 meters with respect to the Late Cretaceous formations of the Eastern Ranges (Potap'yev and Marakhanov, 1974).

The tectonic evolution of the Central Kamchatka basin terrane is tentatively proposed to be related to the development of the Iruney arc of the Sredinny Range terrane and the Eastern Ranges arc of the Eastern Ranges terrane in Late Cretaceous time. Initiation of activity of the two arcs is proposed to have entrapped a fragment of Late Mesozoic oceanic crust. As subduction activity continued, the basin narrowed until in latest Cretaceous time, the accretion of the arcs compressed the entrapped oceanic fragment leading to metamorphism of the upper portion of the oceanic layer, an example of which is exposed in the Khavyven Uplift. The axis of the gravity and magnetic anomalies extending through the basin corresponds to the axis of the folded, uplifted and deformed oceanic layer.

Paleogene and Neogene calc-alkaline volcanics in the basin are probably volcanic products of the Oligocene to Miocene Sredinny Range arc. Volcanic activity in the basin continued through Quaternary time.

EASTERN RANGES TERRANE

The Eastern Ranges include the Valaginsky, Tumrok and Kumroch Ranges and the northern part of the Ganal Range (fig. 2) and are collectively referred to as the Eastern Ranges terrane. The stratigraphy is continuous along the entire length of the ranges and is consistent with it being one tectonic structure. The important features of the terrane are the oceanic crust of the basement overlain by Late Cretaceous to Early Tertiary arc facies. Tertiary sequences are exposed only along the eastern margin of the terrane and consist predominantly of clastics (fig. 19). Extensive Quaternary volcanic cover obscures the older formations.

The basal sequence found in the Valaginsk and Tumrok Ranges is named the Valaginsk series whereas in the Kumroch Range the Vetlovsk and Khapitsk suites are the equivalent of the Valaginsk series. The Khapitsk suite is commonly the name given to the uppermost of four suites of the Valagin series. The Stenovaya series, described in the northern part of the Ganal Range along the southern margin of the Eastern Ranges terrane, is a metamorphic outcrop of the lower sections of the Valagin series. Each of the three basement formations of the various portions of the terrane are considered separately.

The Valagin series has four stratigraphic levels with the lower three being unnamed while the uppermost is called the Khapitsk suite (Rotman et al., 1973). For clarity, the

Figure 19 - Stratigraphy of the Eastern Ranges terrane

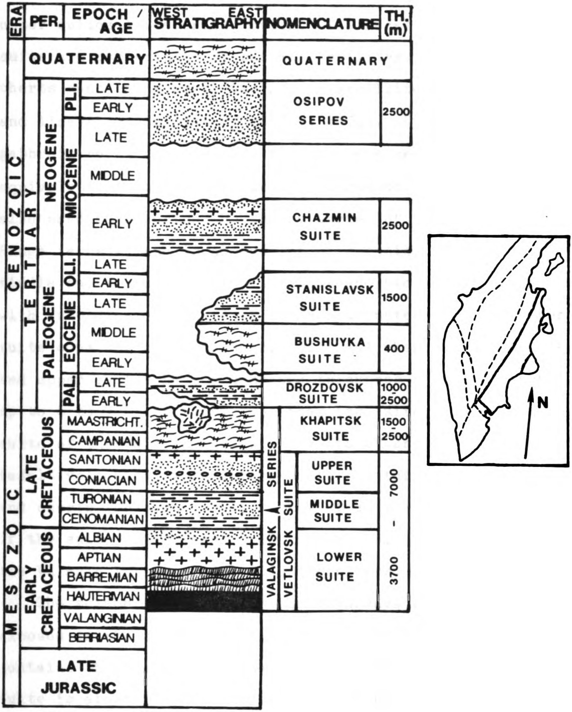
ERA
PER.
EPOCH / AGE
WEST EAST
STRATIGRAPHY
NOMENCLATURE
TH. (m)
QUATERNARY
QUATERNARY
CENOZOIC
TERTIARY
NEOGENE
PLI.
LATE
EARLY
MIOCENE
LATE
MIDDLE
EARLY
OSIPOV SERIES
2500
CHAZMIN SUITE
2500
PALEOGENE
OLI.
LATE
EARLY
EOCENE
LATE
MIDDLE
EARLY
PAL.
LATE
EARLY
STANISLAVSK SUITE
1500
BUSHUYKA SUITE
400
DROZDOVSK SUITE
1000
2500
MESOZOIC
LATE CRETACEOUS
MAASTRICHT.
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
KHAPITSK SUITE
1500
2500
EARLY CRETACEOUS
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
LATE JURASSIC
VALAGINSK SERIES
VETLOVSK SUITE
UPPER SUITE
MIDDLE SUITE
LOWER SUITE
3700 - 7000
N

Figure 19

lower three suites will be called the lower, middle and upper suites in ascending order. The rocks of the lower suite are represented by basalts, spilites, tuffs and cherts containing small amounts of argillite, siltstone, and limestone (Gnibidenko et al., 1974). Diabase and gabbroic rocks are commonly found. This sequence is the equivalent of the "siliceous-volcanogenous formation" term also used to describe the Iruney series of the Sredinny Range terrane, and is an outcrop of oceanic crust. The middle suite consists of sandstones and black argillites with subordinate amounts of tuffaceous material. The upper suite consists of sandstones, tuffs and cherts. The middle and upper suites have a combined thickness that may reach up to 6 to 7 kilometers. The Khapitsk suite, the uppermost suite of the Valagin series, consists of andesite and basalt volcanics, with layers of tuffs, tuffaceous clastics and cherts (Shapiro, 1981; Markov et al., 1969). Thickness of the suite is at least 2500 kilometers. Each suite of the Valagin series grades into the others.

The metamorphic rocks of the Stenovaya series are exposed in the southernmost region of the terrane and contains three suites (Herman et al., 1978). The lower suite is about 1000 meters thick and consists of meta-volcanic rocks, tuffs, lavas and breccias of quartz keratophyre composition, with interbeds of mafic schists, phyllites and quartzites. The middle suite contains interbedded felsic and mafic meta-volcanics 700 to 800 re

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meters thick. The upper suite consists entirely of mafic schists with some phyllites and is at least 1500 meters thick. Generally, the rocks of the series are of epidote-amphibolite metamorphic grade at the Ganal/Eastern Ranges contact. North of the contact, the metamorphic grade of the Stenovaya series decreases (Herman et al., 1978) and grades into unmetamorphosed rocks of the Valaginsk Range (Lebedev et al., 1967), presumably the Valaginsk series. Although the rocks of the Stenovaya series are described as containing a predominance of quartz keratophyre in the lower sections, the genetic association of the keratophyre and the mafic schists, commonly found in upper oceanic layers, correlates with the oceanic crust exposed at the base of the Valaginsk series. Therefore, based on the genetic association and the metamorphic gradient, the Stenovaya series is suggested to be the southernmost exposure of the Valaginsk series that became metamorphosed during an accretionary episode.

In the Kumroch Range, the Vetlovsk suite, as described by Markov et al. (1969), may be divided in three sub-suites. For clarity, the suites will be called the lower, middle and upper sub-suites. The lower sub-suite is represented by diabases, spilites, cherts and tuffs. The middle sub-suite is a sequence of interbedded sandstones and silty argillites, containing calcareous sandstones, limestones and chert. The upper sub-suite consists of fine clastics and limestones with chert interbeds that changes up the section into coarse grained sandstones and conglomerates. The Vetlovsk suite has a total thickness of 3700 to 4000 meters and is conformably overlain by the Khapitsk suite. Rocks of the Khapitsk suite exposed in the Kumroch Range are identical in composition to the exposures of the same suite in the Valaginsky and Tumrok Ranges. The exposures of the Khapitsk suite in the Kumroch Range are, however, 1500 to 1800 meters thick compared to the 2500 meter thickness of the Valaginsk and Tumrok Range exposures.

Thus, comparison of the stratigraphy in the northern Ganal Range, and the Valaginsk, Tumrok and Kumroch Ranges reveals their similarities in that basement material consists of an oceanic layer (the lower suite of the Valaginsk series, the genetic association of the Stenovaya series, and the lower sub-suite of the Vetlovsk suite) overlain by a sequence of fine to coarse clastics (the middle and upper suites of the Valaginsk series and the middle and upper sub-suites of the Vetlovsk suite). Along the entire length of the ranges, these formations are overlain by the intermediate volcanics of the Khapitsk suite.

Ultramafic rocks of various composition are exposed amongst the volcanics of the Khapitsk suite in the Tumrok and Kumrock Ranges (Pushcharovskiy et al., 1983; Rotman et al., 1973; Seliverstov and Tsikunov, 1974; Markovskiy and Rotman, 1971; Krasny, 1964). Rotman et al. (1973)

describes two exposures of the ultramafic rocks in the Tumrok Range. To the northwest and west of the lake lies the "Tolbachinsk" complex consisting of pyroxenites, wehrlites, serpentinites and olivinites. Outcrops of gabbro and gabbro-syenite are common. The "Ostantsovsk" complex lies to the west of the lake and consists of gabbro, gabbro-diorite, harzburgite and dunite. A K-Ar radiometric age date of 80Ma was obtained from the ultramafics of this complex (Rotman et al., 1973). In both complexes, the rocks are described as dikes, sills and pyroclastics although no metamorphic contact zones are described. In addition, the presence of blocks of limestone in the vicinity of the ultramafics (Rotman et al., 1973) indicates the rock association may represent a subduction zone melange complex.

The age of the Valaginsk series and the Vetlovsk suite is based on only a few observations. Fragments of Late Cretaceous Inoceramus found in the upper suite of the Valaginsk series (Rotman et al., 1973) constitute the only paleontological data from these formations. A Late Cretaceous age is also implied by the Paleocene age of the overlying Drozdovsk suite.

The age of the Stenovaya series is also considered to be Late Cretaceous, based on the genetic similarities with the Late Cretaceous Valaginsk series. However, several authors (e.g., Herman et al., 1978; Shul'diner et al., 1979) contend the series is Ordovician, or older, in age, based on one Rb-Sr radiometric age date of 487 Ma obtained from the center of the "least altered plagiogranite porphyry" stock intruding the series. The date is considered questionable due to the genetic relations between the Stenovaya and Valaginsk series that indicate a common tectonic origin and a consequent, inferred Late Cretaceous age for the Stenovaya series. A K-Ar radiometric age of 60 Ma obtained from the same rock (Herman et al., 1978) suggests an Early tertiary age for the granite and a Late Cretaceous or Early Tertiary age for the Stenovaya series.

The Drozdovsk series overlies the Khapitsk suite and consists of alternating beds of sandstones and argillites containing calcareous and sometimes tuffaceous, horizons. Thickness of the suite ranges from 1000 to 2500 meters (Rotman et al., 1973; Markov et al., 1969). The contact between the Drozdovsk and Khapitsk suites is described as both conformable and unconformable (Rotman et al., 1973). The age of the suite is defined by the remains of a Danian to Paleocene benthonic foraminifer assemblage found in the Tumrok Range and a planktonic foraminifer assemblage of Early Paleocene age found in the Valaginsk Range (Serova et al., 1970). The fossils date the Drozdovsk suite and imply a Late Cretaceous age for the underlying Valaginsk series and Vetlovsk suites.

Overlying the Drozdovsk suite with only a minor unconformity, and found only in the areas of the Gamchen

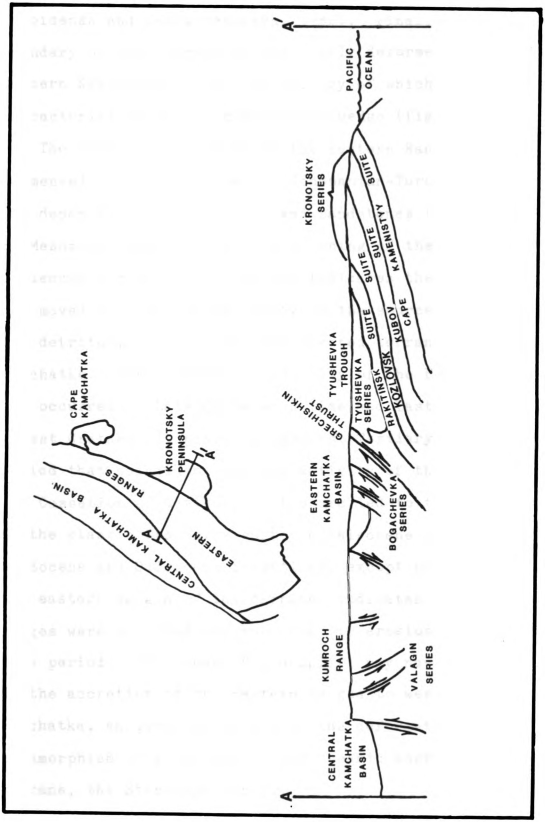
Range, along the eastern margin of the Eastern ranges terrane (fig. 2), are the Bushuyka and Stanislavsk suites. The Bushuyka suite consists of 400 meters of andesitic tuffs and cherts while the conformably overlying Stanislavsk suite consists of 1500 meters of sandstones and siltstones (Shapiro and Seliverstov, 1975). Both suites are devoid of paleontological remains, preventing an accurate dating although a Paleogene age is inferred from the underlying Paleocene Drozdovsk suite and the overlying fine clastics of the Early Miocene Chazhmin suite.

The Late Miocene to Pliocene Osipov series overlies the Chazhmin suite and consists of 2500 meters of clastic sediments. Extensive Quaternary andesite and basalt volcanics in addition to clastics of the same age complete the stratigraphic section of the Eastern Ranges terrane. It should be noted that volcanic arc facies of Late Oligocene and Miocene age, most likely related to contemporaneous deposits found on the Sredinny Range, Ganal and Southern Kamchatka terranes, are found along the southern margin of the Eastern Ranges terrane. Their description is found in the Sredinny Range and Southern Kamchatka terrane sections.

Along the western margin of the terrane lie several large thrust faults dipping southeast 30° to 40° with a displacement of 10 to 12 kilometers (Tsikunov and Petrov, 1973; Tikhonov, 1968). The faults have thrust the Drozdovsk suite over the Khapitsk suite and the Khapitsk suite over the lower sections of the Valaginsk series (Tsikunov and Petrov, 1973; Florenskiy and Florenskiy, 1972). The age of development of the faults is suggested to be Late Cretaceous or Early Tertiary to Middle Miocene, determined on the basis of the faulted Paleogene and Early Miocene rocks but relatively undeformed Late Miocene and younger rocks (Tsikunov and Petrov, 1973; Pushcharovskiy et al., 1983). Folds in the Late Cretaceous to Early Miocene rocks of the terrane trend generally north-south to northeast-southwest (Gnibidenko et al., 1974; Shapiro and Seliverstov, 1975). Along the southern margin of the terrane, the folds trend northwest to southeast, paralleling the Eastern Ranges/Ganal terrane boundary.

The Eastern Ranges terrane is bounded by large faults. The western boundary is described specifically as a normal fault (Legler and Florenskiy, 1976; Florenskiy and Florenskiy, 1972) or generally as a large fault (Tsikunov and Petrov, 1972; Potap'yev and Marakhanov, 1974; Suprunenko, 1976; Erlich, 1979) lying immediately to the west of the previously described system of thrust faults (fig. 20). This fault zone separates the Eastern Ranges terrane from the Central Kamchatka Basin. The southern margin of the Eastern Ranges terrane is a southwesterly dipping thrust fault along which the Ganal terrane is thrust to the north-northeast over the rocks of the Valaginsky Range (Herman et al., 1978). The fault extends from the Central Kamchatka Basin, southeast to the northern

Figure 20 - Cross-section of eastern Kamchatka



CAPE KAMCHATKA
KRONOTSKY PENINSULA
RANGES
BASIN
CENTRAL KAMCHATKA
EASTERN
A
A'
A'
PACIFIC OCEAN
KRONOTSKY SERIES
SUITE
KAMENISTYY
SUITE
SUITE
SUITE
KUBOV
CAPE
TYUSHEVKA TROUGH
TYUSHEVKA SERIES
RAKITINSK
KOZLOVSK
GRECHISHKIN THRUST
EASTERN KAMCHATKA BASIN
BOGACHEVKA SERIES
KUMROCH RANGE
VALAGIN SERIES
CENTRAL KAMCHATKA BASIN
A

Figure 20

shore of the Avacha Inlet (Gnibidenko et al., 1974; Gnibidenko and Svarichevskaya, 1984). Finally, the eastern boundary of the terrane is the highly deformed and faulted Eastern Kamchatka Basin, the geology of which resembles the characteristics of an accretionary wedge (fig. 25).

The tectonic evolution of the Eastern Ranges terrane commenced in Late Cretaceous (Cenomanian-Turonian?) with the deposition of the shales and sandstones (turbidites?) on Mesozoic oceanic crust. Coarsening of the clastic sequences higher in the section indicates the oceanic crust had moved into closer proximity to the source terrane of the detritus, possibly the amalgamated terranes of western Kamchatka. Development and activity of the Eastern Ranges arc occurred in Late Cretaceous time and lasted through latest Cretaceous, possibly earliest Tertiary, time, a period that coincides with the activity of the Iruney arc.

Cessation of activity of the arc led to the deposition of the clastic Drozdovsk suite in Paleocene time. Absence of Eocene and Oligocene formations, except possibly along the eastern margin of the terrane, indicates the Eastern ranges were uplifted and subjected to erosion during this time period. The cause of the uplift may have been related to the accretion of the Eastern Ranges to western Kamchatka, an event which led to the deformation and metamorphism of a portion of the oceanic basement of the terrane, the Stenovaya series.

Minor clastic sedimentation and volcanic activity occurred from Eocene through Early Miocene time. Middle Miocene time was a period of uplift accompanied by extensive thrust faulting and folding of the pre-Middle Miocene rocks of the terrane and was followed by a period of Late Miocene to Pliocene sedimentation. This orogenic activity is related to the accretion of the Kronotsky terrane to the eastern margin of the Eastern ranges and to the development of a new subduction zone at the site of the present day Kuril-Kamchatka trench. Volcanic activity associated with this trench commenced in Pliocene time, but was most extensive during Quaternary time.

GANAL TERRANE

The Ganal terrane, located between the Eastern Ranges and Southern Kamchatka terranes, consists of mafic schists of various metamorphic grades overlain by Tertiary volcanic and clastic sequences (fig. 21).

The exposed basement of the terrane consists of the Ganal series, outcrops of which extend southeast from the Central Kamchatka basin to the northern shoreline of the Avacha Inlet (Gnibidenko et al., 1974; Erlich, 1979). The series is 2500 to 3000 meters thick and is represented by moderate to high grade metamorphic mafic schists containing intercalcations of pelitic schists, quartzites and marbles (Shul'diner et al., 1979). Petrological analyses of the schists indicate the parent rocks of the Ganal series were alkalic to tholeiitic basalt of oceanic origin (Rozen and Markov, 1973). In addition, Tararin (1977) and Gnibidenko et al. (1974) suggest the parent rocks consisted of diabase, spilite, tuffs, andesite porphyry, dacite, siliceous-volcanics, sandstones and limestone. The Oligocene to Quaternary volcanic-sedimentary suites of the Sredinny Range and Southern Kamchatka terranes overlie the Ganal series unconformably and are described in detail in those sections. They include the Oligocene to Middle Miocene Anavgay series, the Late Miocene to Early Pliocene Alney series, the Pliocene Golyga suite and Quaternary sequences. Generally, the rocks of the Ganal series are exposed in the western half of the terrane while the middle

Figure 21 - Stratigraphy of the Ganal terrane

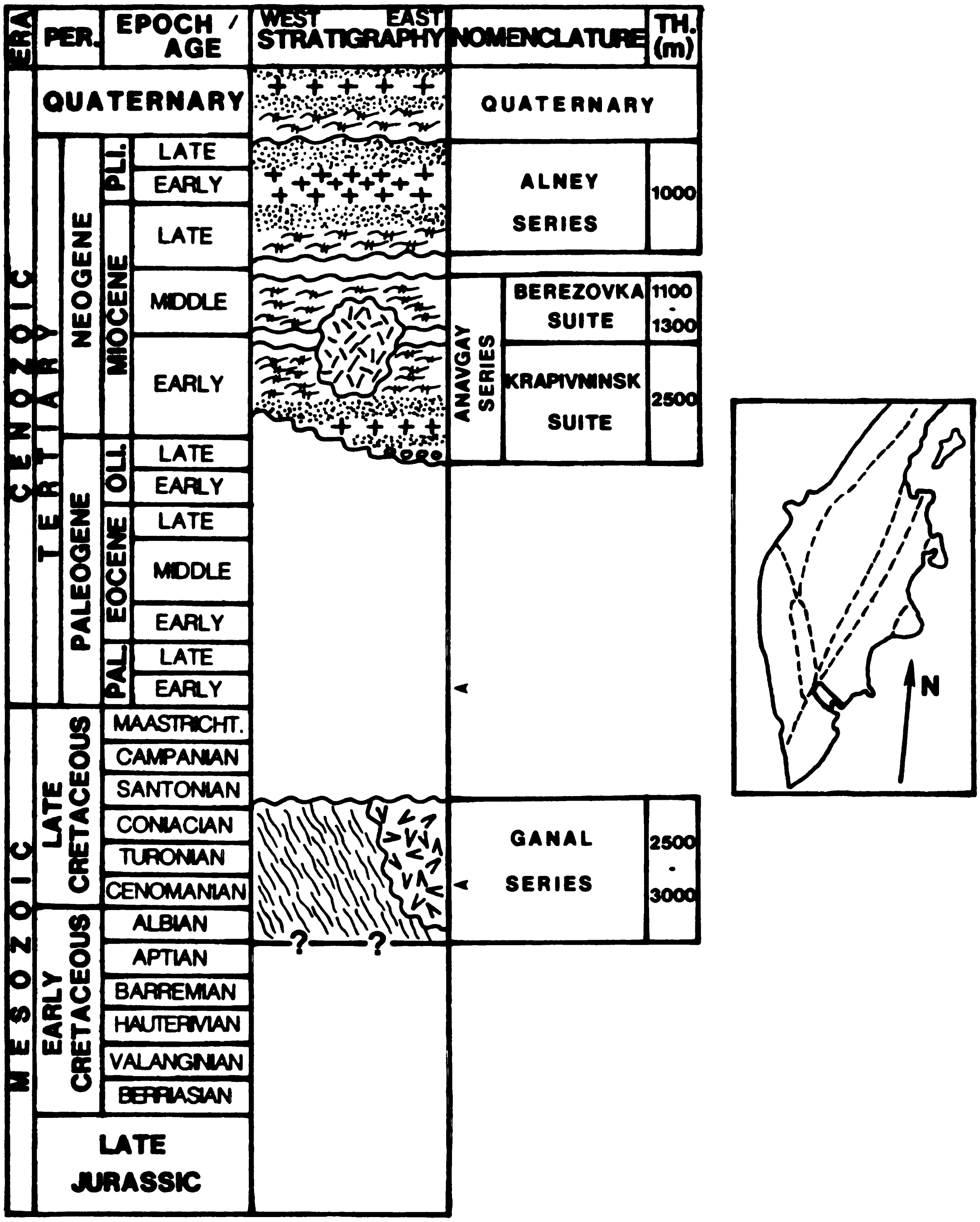

ERA
PER.
EPOCH / AGE
WEST EAST
STRATIGRAPHY
NOMENCLATURE
TH. (m)
QUATERNARY
QUATERNARY
CENOZOIC
TERTIARY
NEOGENE
PLI.
LATE
EARLY
MIOCENE
LATE
MIDDLE
EARLY
ALNEY SERIES
1000
ANAVGAY SERIES
BEREZOVKA SUITE
1100 - 1300
KRAPIVNINSK SUITE
2500
PALEOGENE
OLI.
LATE
EARLY
EOCENE
LATE
MIDDLE
EARLY
PAL.
LATE
EARLY
MESOZOIC
LATE CRETACEOUS
MAASTRICHT.
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
GANAL SERIES
2500 - 3000
EARLY CRETACEOUS
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
LATE JURASSIC
N

Figure 21

and late Tertiary rocks are found in the eastern part of the terrane.

Metamorphic grade of the Ganal series varies from epidote-amphibolite to greenschist facies, exemplified by mineral assemblages found throughout the exposures of the series (Herman et al., 1978; Tararin, 1977; Gnibidenko et al., 1974). Mineral assemblages indicative of epidote-amphibolite facies metamorphism include hornblende, albite, quartz, and epidote. Some of the minerals of the amphibole group are the result of high pressure metamorphism, i.e., blueschist facies (Dobretsov and Kuroda, 1970; Herman et al., 1978; Gnibidenko et al., 1974). Mineral assemblages indicative of greenschist facies metamorphism include albite, epidote, chlorite, quartz, actinolite and biotite. Mineral assemblages of both epidote-amphibolite and greenschist facies metamorphism found in pelitic rocks include biotite, garnet, cordierite, sillimanite, kyanite and staurolite. These minerals are found in pelitic schist, gneisses and marbles.

The age of the Ganal series is constrained only by several K-Ar radiometric age dates. An upper age limit for the series may be assigned as Oligocene, the age of the unconformably overlying Sredinny Range volcanic arc formations. A list of the radiometric and the rock type from which they came is listed in Table 3. Eleven of the dates obtained from granulite, gneiss and gabbro are

Table 3 - Potassium - argon radiometric dates from the Ganal terane

Table 3

ROCK TYPES	AGE (Ma)
granulites	
hypersthene - biotite - garnet gneiss	188,283
biotite - hypersthene gneiss	172
plagiogranite	138
schist	120,121
Ganal Series	
biotite gneiss	94,188
amphibolite	65,95,95
gneiss	69,88
granite	65
gabbro	
gabbro pegmatite	270,314
gabbro norite	93,283
cortlandite	234

scattered throughout the Phanerozoic, from Early Pennsylvanian time to middle Early Cretaceous time and are too varied to suggest a meaning for them. However, five dates, four from the rocks of the Ganal series and one from a gabbro-norite, average 93.2 ± 2.9 Ma, a middle Cenomanian age. In addition, three dates obtained solely from the rocks of the Ganal series average 66.3 ± 1.9 Ma, at the Late Cretaceous/Paleocene time boundary. Unfortunately neither the location of the sample nor the sample types, whether whole rock or mineral, are given in the reference.

Intrusive rocks found in the terrane are predominantly gabbro-norites but also include diabase and plagiogranites. The Yurchik Massif, a major intrusive body of medium grained gabbro-norite, is surrounded by a metamorphic contact aureole along which granulites, consisting of biotite-garnet-cordierite-hypersthene-quartz - plagioclase gneisses and hornfels that also contain clinopyroxene and orthopyroxene, are found. The contact aureole is a few meters up to 30 to 40 meters in width. Grain size of the gabbro-norite pluton becomes fine towards the margins and coarsens towards the center (Herman et al., 1978). Tertiary intrusive rocks include diorite and granodiorites of Miocene age (Krasny, 1964; Lebedev et al., 1967).

The structural features of the Ganal terrane trend northwest-southeast and parallels the contact with the Eastern Ranges terrane. These features include folding, metamorphic fabric and zones of shearing. The Ganal series itself is intensely foliated and strongly schistose, and accompanied by abundant zones of shearing and crushing (Lebedev et al., 1967; Tararin, 1977). The contact with the Eastern Ranges terrane is described as a thrust fault along which intense foliation of the associated rocks and mylonites are present (Herman et al., 1978). The thrust plane dips southwest 40° to 50°, parallel to folds in the Stenovaya series of the southern margin of the Eastern Ranges terrane. The western margin of the terrane is the narrow, southern extremity of the Central Kamchatka Basin, commonly described as a graben in this region and bounded by normal faults (Erlich, 1979). The southern margin of the terrane is bounded by a large fault of undetermined character exposed in the Nachikinsk anticline (Gnibidenko et al., 1974). Across this fault lies the Southern Kamchatka terrane.

On the basis of the available data, the basement of the Ganal terrane, the Ganal series, is suggested to represent a portion of an oceanic layer of Early to middle Cretaceous age, based on the upper age limit set by the middle Cretaceous (Cenomanian) grouping of K-Ar age dates. Metamorphism of the series into moderate and high grade metamorphic schists occurred during two primary events. The events are dated by the clustering of dates at 93 and 66 Ma, middle Cenomanian and latest Cretaceous/earliest Tertiary time. The first event is related to the intrusion of the majority of the gabbro-norites and diabases found throughout the Ganal series. A mechanism for this event is unknown, but due to the suggested oceanic character of the rocks, may be related to the formation of the rocks at a ridge crest or hot spot volcanic center, or subduction zone/island arc igneous activity. The second event, a regional metamorphism (Tararin, 1977; Herman et al., 1978), occurred in response to the accretion of the Ganal and Eastern Ranges terranes. Compressive and shear stresses applied to the Ganal series during the accretionary episode resulted in intense shearing and deformation of the rocks. This event also affected the southern margin of the Eastern Ranges terrane producing the metamorphic Stenovaya series.

Uplift and erosion of the Ganal terrane occurred during Paleocene, Eocene and Oligocene time as evidenced by the lack of formations of this age. Development of the middle Tertiary Sredinny Range arc in Oligocene time led to the eruption and deposition of volcanic and sedimentary suites. Miocene igneous plutons in the Ganal terrane are related to this period of arc activity. Volcanism and sedimentation continued through Quaternary time.

SOUTHERN KAMCHATKA TERRANE

The southern part of Kamchatka Peninsula, bounded by the Ganal terrane to the north and the Malkinsk and Kvakhon terrane to the west, is the Southern Kamchatka terrane. Late Cretaceous arc formations that overlie deep water sediments are unconformably overlain by middle and late Tertiary volcanic rocks (fig. 22). The Tertiary stratigraphic column of the terrane is very similar to the column of the Sredinny Range terrane and suggests the possibility that these regions have been one continuous feature since at least Oligocene time.

The basement of the terrane is indicated to be oceanic crust by exposure of a deep water sedimentary sequence of sandstones, siltstones and argillites with layers of tuffs, siliceous shales, jasper and calcareous sandstone, that are exposed in the northwest part of the terrane (Krasny, 1964; Gnibidenko et al., 1974). Calc-alkaline volcanics of Late Cretaceous age overlie the sedimentary sequence and are exposed in the same region of the terrane (Herman et al., 1978; Krasny, 1964). The volcanics are dated by fossil remains of the mollusc Inoceramus Schmidti Mich., of Santonian to Campanian age (Herman et al., 1978). Herman et al. (1978) names the sequence the Iruney series. Because the Iruney series is an oceanic layer in western Kamchatka, the calc-alkaline arc formations of Late Cretaceous age in the Southern Kamchatka terrane are more properly correlated with either the Kirganik or Khapitsk

Figure 22 - Stratigraphy of the Southern Kamchatka terrane

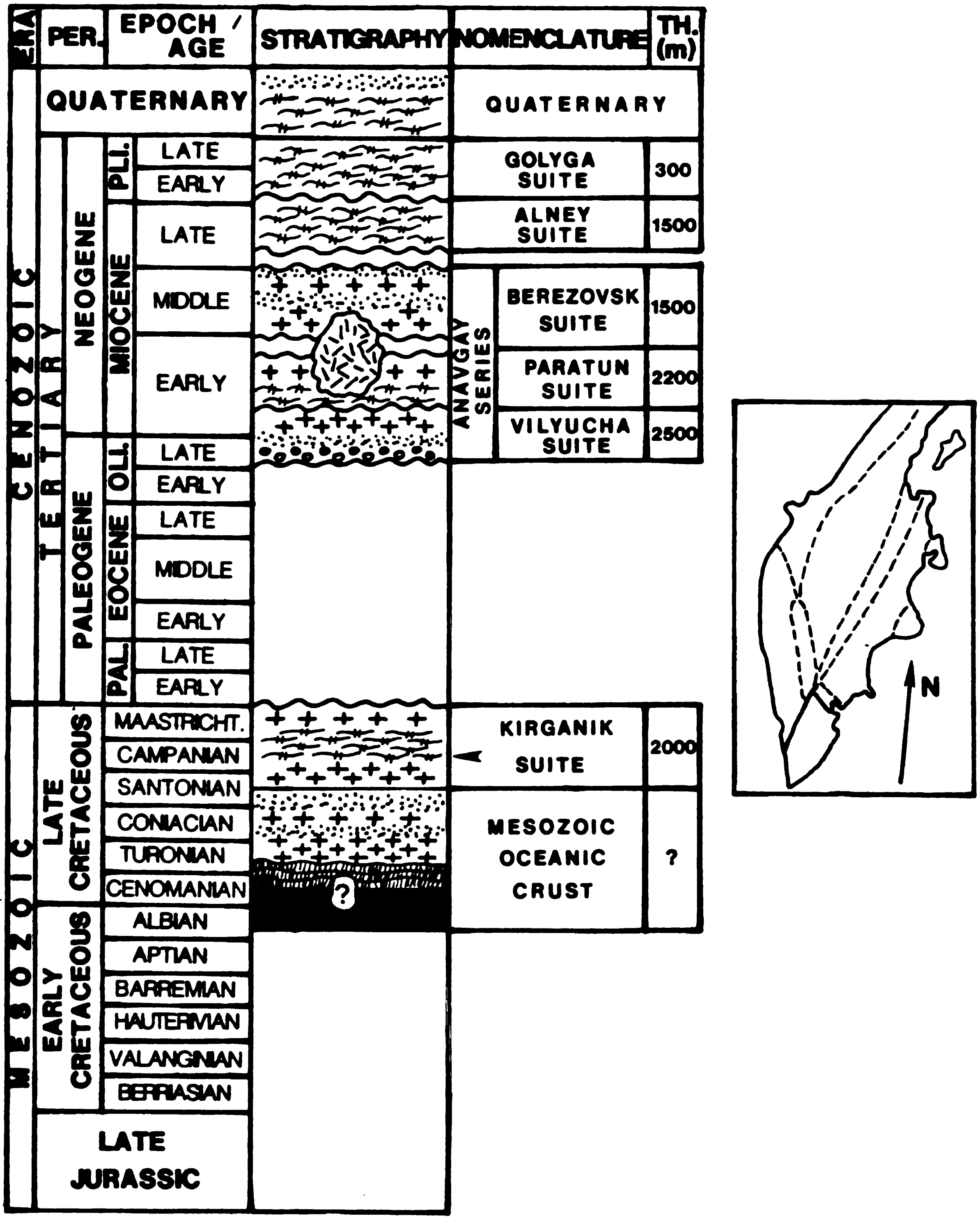

ERA
PER.
EPOCH / AGE
STRATIGRAPHY
NOMENCLATURE
TH. (m)
QUATERNARY
QUATERNARY
CENOZOIC
TERTIARY
NEOGENE
PLI.
LATE
EARLY
GOLYGA SUITE
300
MIOCENE
LATE
ALNEY SUITE
1500
MIDDLE
BEREZOVSK SUITE
1500
EARLY
PARATUN SUITE
2200
ANAVGAY SERIES
OLI.
LATE
VILYUCHA SUITE
2500
EARLY
PALEOGENE
EOCENE
LATE
MIDDLE
EARLY
PAL.
LATE
EARLY
MESOZOIC
LATE CRETACEOUS
MAASTRICHT.
CAMPANIAN
KIRGANIK SUITE
2000
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
MESOZOIC OCEANIC CRUST
?
EARLY CRETACEOUS
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
LATE JURASSIC
N

Figure 22

suites of the Sredinny Range and Eastern Ranges terranes, respectively.

Tertiary sequences are exposed throughout the terrane in contrast to the limited outcrops of Late Cretaceous rocks. The Anavgay series unconformably overlies the older formations and can be divided into three separate suites. The Vilyucha suite is of Late Oligocene to Early Miocene age and consists of sandstones, argillites and conglomerates, sometimes interbedded in a flysch-like manner, with layers of tuffs in the upper part of the suite. The base of the suite is not exposed but its visible thickness is 2500 meters (Aprelkov, 1971). Pebbles found in the conglomerates consist of fragments of greenschists, phyllites and granites and are erosional remnants of the Ganal terrane (Aprelkov, 1971). The Paratun suite, about 2200 meters thick, unconformably overlies the Vilyucha suite and consists of basalt, andesite and dacite flows alternating with beds of tuff and tuffaceous sandstones and conglomerates. Again, the pebbles of the conglomerates commonly consist of fragments of greenschists, phyllites and granites. The Middle Miocene Berezovsk suite, the uppermost suite of the Anavgay series, unconformably overlies the Vilyucha suite and is about 1500 meters thick. The suite consists of dacitic and andesitic pyroclastics with subordinate amounts of sandstone and siltstones. Abundant faunal remains date each of the suites of the series. The Late Miocene to

Pliocene Alney series unconformably overlies the Anavgay series and is represented by basalts, andesites and their associated pyroclastics. Acidic (felsic) volcanics are common in the upper part of the suite. The suite is dated by floral and faunal remains and has an observed thickness of up to 1500 meters. The unconformably overlying Golyga suite conists of ignimbrites and tuffs, up to 300 meters thick. Radiometric age dates of the volcanics range from 6 to 12 Ma (Aprelkov, 1971), Late Miocene to Pliocene age. Quaternary volcanic deposits complete the stratigraphy of the Southern Kamchatka terrane and consist of basalts, andesites, dacites and associated pyroclastics.

The structural features of the terrane trend in two primary directions. The Nachikinsk anticline, located in the northern part of the terrane along the boundary with the Ganal terrane, contains numerous faults and folds trending northwest to southeast, parallel to the Southern Kamchatka/Ganal boundary zone (Aprelkov, 1971). Along the eastern margin of the terrane, structural features of the South Kamchatka anticlinorium trend in a northeasterly direction, parallel to the coastline and the Kuril-Kamchatka trench (Aprelkov, 1971).

Dioritic and granodioritic plutons of Miocene age and granitic plutions of Miocene and Pliocene age are widespread in the northern, central and eastern regions of the terrane (Aprelkov, 1971; Krasny, 1964). They intrude the Oligocene and Miocene formations, primarily the Anavgay series.

The northern boundary of the Southern Kamchatka terrane, the Nachikinsk anticline, contains a major fault zone, across which lies the Ganal terrane. The zone extends southeast and reaches the coast south of the Avacha Inlet. To the northwest, the fault separates the high grade metamorphic rocks of the Ganal series from the Late Cretaceous calc-alkaline volcanics and is described as a normal fault (Herman et al., 1978). The western margin of the terrane is a narrow basin, the Golyga trough, that trends northeast and is filled with 5000 to 6000 meters of Late Paleogene to Quaternary volcanic and clastic sequences (Smirnov, 1971). The trough continues south into the Sea of Okhotsk (Gnibidenko and Khvedchuk, 1982) and may possibly extend north to connect with the trough located along the western margin of the Central Kamchatka Basin. West of the trough lies the Kvakhon terrane.

The northwestern margin of the terrane is the southern extension of the Central Kamchatka Basin, in this region, a normal faulted graben feature across which lies the metamorphic complex of the Malkinsk terrane. Although no direct evidence of a major fault zone is found along the western margin of the Southern Kamchatka terrane, the existence of a suture/boundary zone may be inferred from the contrasting rock types found on the opposite sides of the Central Kamchatka Basin.

The development of the Southern Kamchatka terrane commenced with the deposition of deepwater sediments of Late Cretaceous age possibly on oceanic crust, and are overlain by formations of a Late Cretaceous arc. The presence of the arc formations of the same age in the Sredinny Range, Eastern Ranges and Southern Kamchatka terranes indicates that either the Iruney or Eastern Ranges arcs extended into the region of Southern Kamchatka. Lack of Paleocene and Eocene formations in the terrane are the result of a period of Early Tertiary uplift. Transgression and development of the Oligocene to Miocene arc formations were contemporaneous with the development of the Sredinny Range volcanic arc and indicates the continuity between these regions. In addition, the arc volcanics of this period and their related intrusives are also found in the Ganal terrane and the southern area of the Eastern Ranges terrane. Volcanic activity in the Southern Kamchatka terrane continued through Quaternary time.

CAPE KAMCHATKA TERRANE

The Cape Kamchatka terrane is a Late Cretaceous or Early Tertiary oceanic sequence overlain by Tertiary volcanic and sedimentary sequences (fig. 23). A Late Cretaceous ophiolite suite is thrust over the southern margin of the cape and may represent a fragment of the basement of the terrane. Structural and stratigraphic data indicate the Cape Kamchatka terrane is distinct from the Eastern ranges terrane but is continuous with the Komandorskie Islands of the western Aleutian Island arc.

Cape Kamchatka may be divided into separate northern and southern geological provinces. Exposed in the northern two-thirds of the terrane is the Stolbovsk series that includes, from bottom to top, the Tarkhovsk, Vereschchagin, Rifovsk and Baklanov suites (Markov et al., 1969). The Tarkhovsk suite consists of pillow basalts, tuffs and cherts and tuffaceous and siliceous argillites, with a thickness of 1300 to 1600 meters. Lack of paleontological data on the suite prevents an accurate age estimate but, the Paleocene age of the conformably overlying Vereshchagin suite suggests a Late Cretaceous or Paleocene age for the Tarkhovsk suite. The Vereshchagin suite consists of alternating coarse and fine clastics with conglomerates and pyroclastic material. Siliceous tuffs are found at the base of the suite. The suite is up to 4000 meters thick and is dated as Paleocene to Eocene on the basis flora and fauna found at the top of the section. The conformably

Figure 23 - Stratigraphy of the Cape Kamchatka terrane

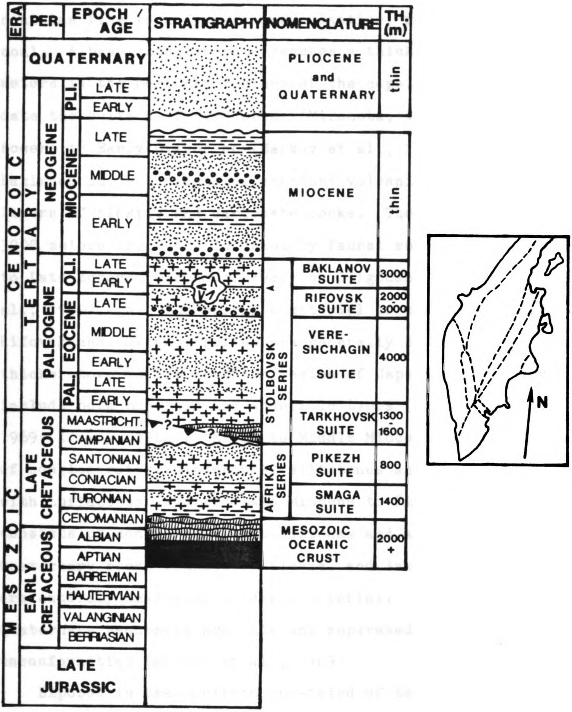

ERA
PER.
EPOCH / AGE
STRATIGRAPHY
NOMENCLATURE
TH. (m)
CENOZOIC
TERTIARY
QUATERNARY
NEOGENE
PLI.
LATE
EARLY
MIOCENE
LATE
MIDDLE
EARLY
PALEOGENE
OLI.
LATE
EARLY
EOCENE
LATE
MIDDLE
EARLY
PAL.
LATE
EARLY
MESOZOIC
LATE CRETACEOUS
MAASTRICHT.
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
EARLY CRETACEOUS
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
LATE JURASSIC
PLIOCENE and QUATERNARY
thin
MIOCENE
thin
STOLBOVSK SERIES
BAKLANOV SUITE
3000
RIFOVSK SUITE
2000 - 3000
VERE-SHCHAGIN SUITE
4000
TARKHOVSK SUITE
1300 - 1600
AFRIKA SERIES
PIKEZH SUITE
800
SMAGA SUITE
1400
MESOZOIC OCEANIC CRUST
2000 +
N

Figure 23

overlying Rifovsk suite, 2000 to 3000 meters thick, contains fine to medium grained clastics, marls, tuffs and coal. A basal conglomerate reaches a thickness of 320 meters in the northern regions of the cape. Faunal remains date the suite as Early Eocene (Mironoba, 1982) or Late Eocene to Early Oligocene (Markov et al., 1969). The Baklanov suite consists of abundant volcanic rocks with layers of clastic and carbonate rocks. The suite is up to 3000 meters thick and is dated by faunal remains of Middle to Late Eocene (Mironoba, 1982) or Oligocene (Markov et al., 1969) age. The volcanic material of the Vereshchagin, Rifovsk and Baklanov suites are generally coarser and thicker towards the northern region of Cape Kamchatka and include both basaltic and andesitic types (Markov et al., 1969; Krasny, 1964). Early to Middle Miocene rocks consist of conglomerates, sandstones, siltstones and argillites with tuffaceous layers. Late Miocene to Pliocene rocks consists of conglomerates, sandstones and argillites. Quaternary rocks consist of fluvial and lake deposits and are entirely devoid of volcanic material. The Neogene and Quaternary sequences are thin and separated by numerous unconformities (Markov et al., 1969).

Exposed in the southern one-third of the terrane is an ophiolite sequence with overlying sedimentary rocks. The lower section of the suite includes dunites, gabbros and serpentinites overlain by gabbros and pillow basalts that are extensively intruded by gabbro and diabase dikes

(Markov et al., 1972). Serpentinites and serpentinization of the ultramafics is common. The upper section of the ophiolite suite is named the Afrika series and is divided into the Smaga and Pikezh suites (Khotin, 1972). The Smaga suite, approximately 1400 meters thick, consists of argillaceous and silty tuffs with layers and lenses of cherts, carbonates and basalts, spilites and tuffs. The Pikezh suite may be subdivided into two subsuites with differing character. The lower subsuite, 400 meters thick, conformably overlies the Smaga suite and includes tuffaceous and siliceous clastics with lenses of chert and clastics. The upper subsuite, 400 meters thick, is represented by fine and medium grained sandstones with interbeds of black mudstone. Foraminifera from carbonate rocks of the Afrika series and spores and pollen from the Pikezh suite indicate a Late Cretaceous age for the series and a Cretaceous age for the underlying ophiolite sequence. Tertiary sequences in the southern region of the terrane consist only of Miocene, Pliocene and Quaternary rocks of the same composition of the contemporaneous deposits of the northern part of the terrane. Paleocene through Oligocene aged rocks are absent.

The Pikezh fault zone separates the terrane in its northern and southern provinces. The zone is seven to eight kilometers wide on the southeast coast of the cape, where it is identified geologically, but narrows to a width of a few hundred meters to the northwest. The zone continues northwest to the Ust-Kamchatka fault zone and is identified by a linear zone of geophysical anomalies. A small outcrop of ultramafics and gabbros exposed on the northwest shoreline of Lake Nerpich'ye is suggested to be related to the fault zone. Crushed, highly altered rocks with a blue fault gouge and serpentinite inclusions are found where the Pikezh fault zone is exposed.

Structurally, the southern and northern portions of the cape differ markedly. In the southern region, several thrust faults are found amongst the rocks of the ophiolite suite and the Afrika series. The faults strike northwest and vary in dip from 25° to nearly vertical. The fault zones are 20 to 30 meters wide containing deformed, crushed and altered rocks and blocks of serpentinized ultramafics. Structural trends in the northern part of the terrane trend generally in the same direction, northwest, but the degree and intensity of faulting is less. Two reverse faults are present that have planes dipping to the southwest. Strike-slip faults of both left and right lateral motion are common. Some fault planes are associated with gabbro and gabbro-diabase dikes up to 3 meters in width. Strikes of folds follow the northwest trends of the fault zones.

Radiometric age dates from the cape include a K-Ar (?) date of 36 Ma (Early Oligocene) from a gabbroic dike found in the northern part of the peninsula. Three dates form the ophiolite exposure averaging 900 Ma were obtained by using the K-Ar method (Vysotsky and Gracheva, 1981) and are considered to be unreliable due to the Late Cretaceous age of the deepwater sediments overlying the suite.

The western margin of the terrane is the Eastern Kamchatka Basin (fig. 25), an accretionary wedge cut by thrust faults (see Eastern Kamchatka basin section). The basin and the major thrust fault associated with it, the Grechishkin thrust, extend from southwestern Kronotsky Peninsula north into the Komandorsky Basin of the Bering Sea. The basin separates the Cape Kamchatka and Kronotsky terranes from the Eastern Ranges terrane. The terrane is bounded on the north by the Bering Sea and on the south by the Pacific Ocean.

The development of the Cape Kamchatka terrane commenced in Late Cretaceous or Early Tertiary time with the formation of the oceanic crust exposed in the terrane. The age of the oceanic basement of the northern block, represented by the Tarkhovsk suite, is Late Cretaceous or Paleocene, and is not too different from the Late Cretaceous age of the Afrika series. Therefore, it is difficult to determine whether the ophiolite exposure of the southern part of the terrane is allochthonous in the sense that it had a completely different place of origin than the oceanic crust of the northern block or if it is allochthonous in the sense that it is an uplifted block of the oceanic crust of the northern block. If it is truly allochthonous, it may be considered an individual terrane but lack of data precludes this determination. Time of uplift (or acretion) of the block cannot be constrained. However, such an event may lead to the deposition of abundant conglomerates, such as is observed at the base of the Early Eocene Rifovsk suite.

Volcanic activity and sedimentation of the terrane continued throughout Paleocene and Eocene time and was followed by a Late Eocene or Early Oligocene to Late Oligocene hiatus. Intrusion of gabbroic dikes occurred towards the beginning of this period in Early Oligocene time. Minor clastic sedimentation resumed in Miocene time and continued through Quaternary time.

KRONOTSKY TERRANE

The stratigraphy of the Kronotsky terrane consists of Late Cretaceous to Oligocene high alumina tholeiitic and alkaline basalts indicative of an island arc overlain by middle and late Tertiary sedimentary sequences (fig. 24).

The Cape Kamenistyy suite lies at the base of the terrane and consists of layers of basalts, tuffs and tuffaceous clastics with less common andesite and andesite-basalt volcanics (Pushcharovskiy et al., 1983; Sadreev and Dolmatov, 1965). The suite is broken into lower and upper slabs by large thrust faults. Siliceous tuffs of the lower slab contain Coniacian and Campanian radiolaria while the upper slab contains Maastrichtian to Early Paleocene radiolaria (Pushcharovskiy et al., 1983). The basalts are high alumina tholeiitic basalts commonly found in island arcs (Pushcharovskiy et al., 1983). A serpentinite melange made up of harzburgites, wehrlites, lherzolite, amphibolites, gabbro-norites and gabbros is found along the fault planes and be ophiolite fragments. Unconformably overlying the Cape Kamenistyy suite is the Kronotsky series, divided into the Kubovsk and Kozlovsk suites. The Kubovsk suite is further subdivided into lower and upper subsuites. The lower subsuite consists of basalts, tuffs and tuffaceous and calcareous clastics with layers of chert and has a thickness of 1300 meters. Faunal remains of foraminifera, radiolarians and mollusks are Paleocene to Early Eocene age. The upper subsuite consists

Figure 24 - Stratigraphy of the Kronotsky terrane

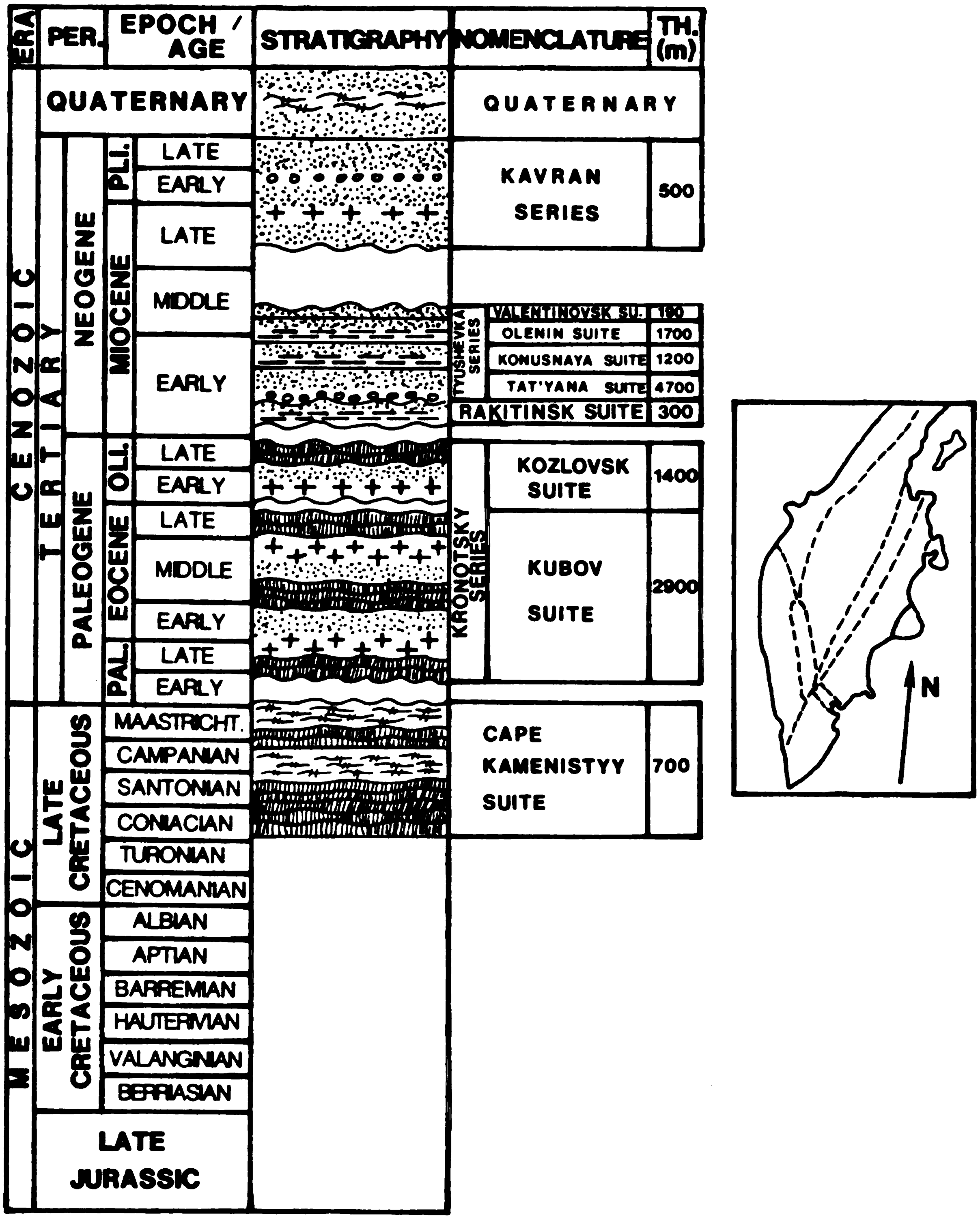

ERA
PER.
EPOCH / AGE
STRATIGRAPHY
NOMENCLATURE
TH. (m)
QUATERNARY
QUATERNARY
CENOZOIC
TERTIARY
NEOGENE
PLI.
LATE
EARLY
KAVRAN SERIES
500
MIOCENE
LATE
MIDDLE
EARLY
TYUSHEVKA SERIES
VALENTINOVSK SU.
190
OLENIN SUITE
1700
KONUSNAYA SUITE
1200
TAT'YANA SUITE
4700
RAKITINSK SUITE
300
PALEOGENE
OLI.
LATE
EARLY
KRONOTSKY SERIES
KOZLOVSK SUITE
1400
EOCENE
LATE
MIDDLE
EARLY
KUBOV SUITE
2900
PAL.
LATE
EARLY
MESOZOIC
LATE CRETACEOUS
MAASTRICHT.
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
CAPE KAMENISTYY SUITE
700
EARLY CRETACEOUS
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
LATE JURASSIC
N

Figure 24

of basalts, tuffs and tuffaceous clastics containing chert and carbonate layers and has a thickness of 1600 meters. Faunal remains are lacking but an Eocene to Early Oligocene age is inferred from the ages of the overlying and underlying suites. The Kozlovsk suite, the upper part of the Kronotsky series, overlies the Kubovsk suite with a minor unconformity and consists of pillow basalts, tuffs and tuffaceous clastics with a thickness of 1400 meters. Alkali basalt flows are found at the top of the Kozlovsk suite (Suprunenko and Markovskiy, 1973). Remains of mollusks of Late Oligocene age found in clastic material at the top of the section date the suite. Examination of the chemistry of the basalts of the Kronotsky series indicate their similarity to high alumina island arc basalts (Rotman and Markovskiy, 1968; Suprunenko, 1972; Suprunenko and Markovskiy, 1973). Dikes of gabbro and diabase intrude the Kronotsky series and are, most likely, old feeder channels for the extensive basalt flows found throughout the series (Sadreev and Dolmatov, 1965). In addition, the number of basalt flows increases from the bottom to the top of the section.

Unconformably and transgressively overlying the volcanic formations of the Kronotsky series is the Rakitinsk suite of Early Miocene age. The suite consists of sandstones, siltstones with chert layers, argillite, tuff and conglomerate. Unconformably overlying the Rakitinsk suite is the Early to Middle Miocene Tyushevka series that includes the Tat'yana, Konusnaya, Olenin and Valentinovsk suites (Mironoba, 1982). In the Kronotsky terrane, the Tyushevka series is found in a narrow basin trending generally north-south that is bounded by outcrops of the Kronotsky series and Rakitinsk suite on the east and by the Grechishkin overthrust belt to the west. The basin extends from southwest of Kronotsky Peninsula to northwest of Cape Kamchatka. The overthrust belt separates the Kronotsky and Cape Kamchatka terranes from the East Kamchatka Basin.

The lower portion of the Tat'yana suite is predominantly sandstones and gravelites, with a thickness of 1700 meters. The upper section of the suite is a flysch sequence consisting of interbedded sandstones and argillites with a thickness of 3000 meters. The lower and upper sections of the Tat'yana suite are synonymous with the Tundrovsk and Talovsk suites, respectively (Mironoba, 1982). The interbedded sandstones and argillites of the Konusnaya suite have a thickness of 1200 meters and conformably overlies the Tat'yana suite. The Olenin suite is conformable on the Konusnaya suite and consists of a rhythmic alternation of sandstone and siltstone, with lesser amounts of argillite and tuff and a thickness that varies from 200 to 1700 meters. The Valentinovsk suite, the uppermost suite of the Tyushevka series consists of a lower section of sandstones, 50 meters thick and an upper section of argillite and diatomite, 140 meters thick. A major unconformity separates the Tyushevka series from the overlying, faunally dated Kavran series, of Late Miocene to Pliocene age. The Kavran series consists of 500 meters of argillites, conglomerates, sandstones sometimes interbedded with lignites and tuff-breccias. Quaternary andesites, andesite-basalts, basalts and their associted tuffs complete the stratigraphic column of the Kronotsky terrane.

The bedding of the Kronotsky series and Rakitinsk suite dips northwest 5 to 20 degrees in a monoclinal fashion. Folds present are described as gentle but sometimes the limbs dip 40 to 50 degrees when located near faults (Shapiro and Seliverstov, 1975). Deformation of the Tyushevka series is more intense, due to the proximity of the exposures to the Grechishkin overthrust. Folds trend northeast with their northwestern limbs dipping 30° to 35° while the southeastern limbs have very steep dips or are vertical. The folds are cut by reverse faults with beds commonly overturned in the vicinity of the overthrust. In contrast, the Late Miocene and Pliocene formations are undeformed and horizontal (Shapiro and Seliverstov, 1975).

The regional extent of the Kronotsky terrane is difficult to determine. Outcrops of blocks of basaltic material found near the Tret'ya River mouth on the Kamchatka Bay (fig. 2) in close proximity to the Grechishkin overthrust zone are similar to the Kronotsky basalts (Shapiro, 1980). In addition, clasts of basaltic rocks found in the Tyushevka series in the same area are also similar to the Kronotsky basalts. It is possible, then, that the rocks of the terrane extend into this region of the Kamchatka Bay. Geophysical data indicate a similar situation (fig. 18 and 26). These data delineate the Grechishkin thrust as a line separating low gravity (Δg) and magnetic (ΔTa) anomalies on the west from high gravity and magnetic anomalies on the east (Suprunenko, 1971). The trace coincides with the geological exposure of the thrust zone from Cape Kamchatka to just south of Kronotsky Peninsula, but then veers sharply southeast and narrow moving into Kronotsky Bay and into the Pacific Ocean. To the north of Kronotsky Peninsula, the anomalies narrow up to the vicinity of Cape Kamchatka. The western boundary of the anomalies closely follows the coastline in the Kamchatka Bay and thus, the trace of the Grechishkin thrust belt. Therefore, assuming the geophysical anomalies outline the mafic volcanic rocks of the Kronotsky series, these data provide an approximation to the extent of the Kronotsky terrane.

The tectonic evolution of the Kronotsky terrane commenced in Late Cretaceous time with the eruption and deposition of the Cape Kamenistyy suite. Basalts of the suite are high alumina island arc basalts similar to the overlying high alumina island arc basalts. The thrust faulted structure of the Cape Kamenistyy suite suggests the possibility that the suite, or the overlying Kronotsky series, may be allochthonous.

Volcanic activity of the Kronotsky series lasted from Paleocene to Oligocene time. Clastic layers in the series indicate the rocks may have been above sea level and subjected to erosion. Based on the geochemistry of the basalts of the Kronotsky series, they represent high alumina basalts of the type found in island arcs. Magnetic anomalies outline the boundary of the Kronotsky series. Volcanic activity ceased in Oligocene time and was followed by a hiatus until Early Miocene time, when deposition of the Rakitinsk and Tyushevka series occurred. A Middle Miocene period of orogeny and uplift is indicated by the deformation of the Tyushevka series and angular unconformity separating the Tyushevka series from the undeformed and horizontal overlying Late Miocene and Pliocene deposits. The basin in which the Tyushevka series was deposited and the major unconformity that separates Early and Late Miocene rocks are the results of the accretion of the Kronotsky and Eastern Ranges terrane in Middle Miocene time. The Tyushevka trough is proposed to be an inter-terrane basin that formed and filled in with sedimentary rocks during the approach and accretion of the two terranes.

EASTERN KAMCHATKA BASIN

The Eastern Kamchatka Basin lies between the Eastern Ranges terrane on the west and the Kronotsky and Cape Kamchatka terranes on the east (fig. 20). The basin contains a thick, highly deformed sedimentary sequence of Oligocene and younger age resembling an accretionary wedge (fig. 25). The Grechishkin overthrust zone is located along the eastern margin of the basin.

The oldest sequence of the basin consists of fine to coarse clastic sediments containing some tuff (Mironoba, 1982). Several names have been proposed for this formation including the Tundrovsk suite (Shapiro and Seliverstov, 1975), the Drozdovsk and Stanislavsk suites (Suprunenko, 1977) and the Bogachevka series (Fedynskiy and Levin, 1970). The name Bogachevka series will be adopted in this paper due to its predominance in the Soviet literature.

The age of the Bogachevka series is unknown but is suggested to be Oligocene to Early Miocene (Shapiro and Seliverstov, 1975). Paleontological remains are sparse or absent. The Chazhmin suite unconformably overlies the western exposures of the Bogachevka series and consists of argillite, siltstone, sandstone, chert and tuff and is 2500 meters thick. Faunal remains of Early Miocene age date the suite. The Early to Middle Miocene Tyushevka series unconformably overlies the Chazhmin suite and includes each

Figure 25 - Stratigraphy of the Eastern Kamchatka Basin

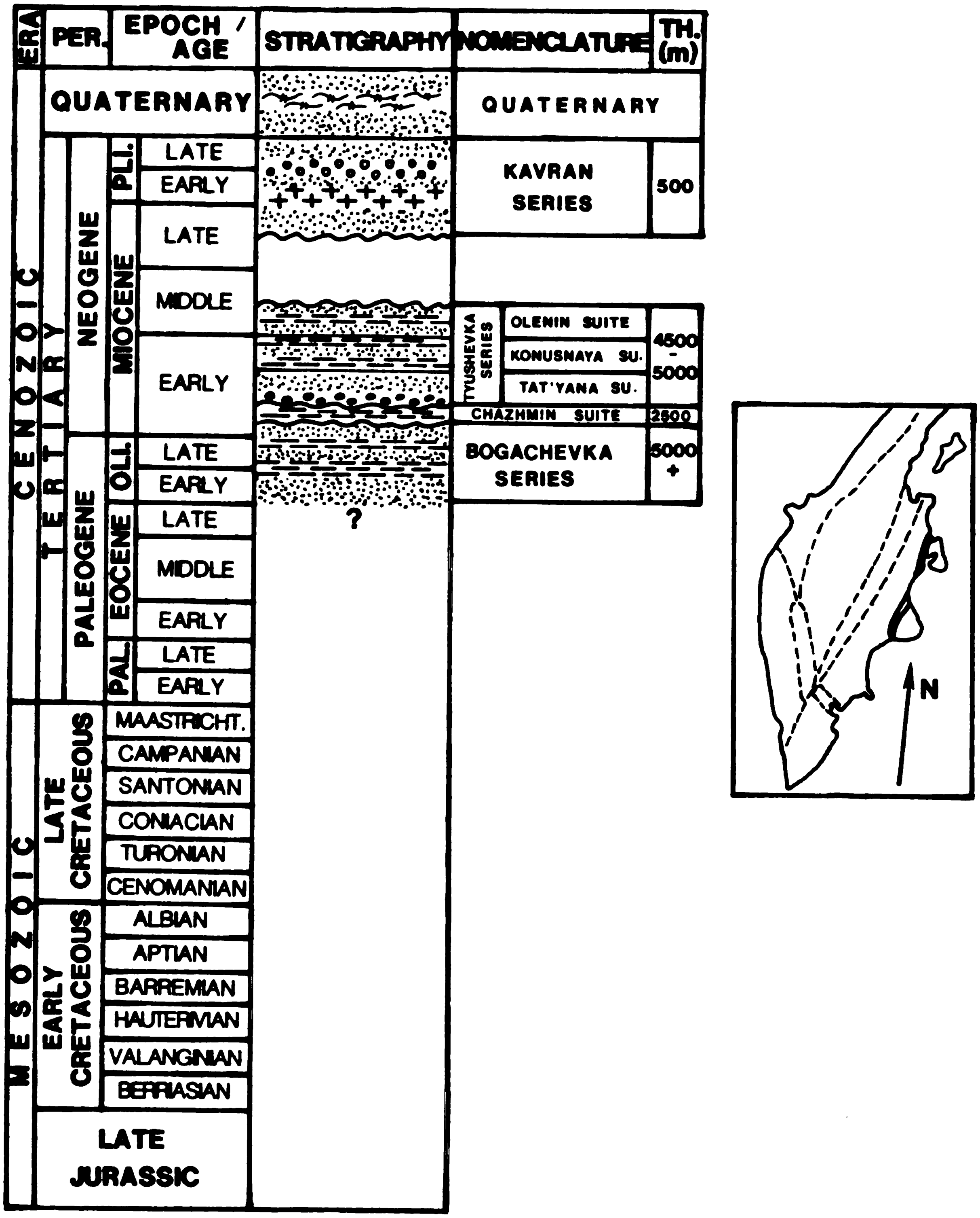

ERA
PER.
EPOCH / AGE
STRATIGRAPHY
NOMENCLATURE
TH. (m)
QUATERNARY
QUATERNARY
CENOZOIC
TERTIARY
NEOGENE
PLI.
LATE
EARLY
KAVRAN SERIES
500
MIOCENE
LATE
MIDDLE
EARLY
TYUSHEVKA SERIES
OLENIN SUITE
KONUSNAYA SU.
TAT'YANA SU.
4500 - 5000
CHAZHMIN SUITE
2500
PALEOGENE
OLI.
LATE
EARLY
BOGACHEVKA SERIES
5000 +
?
EOCENE
LATE
MIDDLE
EARLY
PAL.
LATE
EARLY
MESOZOIC
LATE CRETACEOUS
MAASTRICHT.
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
EARLY CRETACEOUS
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
LATE JURASSIC
N

Figure 25

of the previously described suites except for the Valentinovskaya suite (Mironoba, 1982; Shapiro and Seliverstov, 1975). Late Miocene and Pliocene clastic Kavran series and Quaternary volcanics and clastics complete the stratigraphy of the Eastern Kamchatka Basin.

The structure of the eastern Kamchatka Basin is very complicated. Each formation of the basin up to and including the Middle Miocene suites of the Tyushevka series are cut by numerous imbricate reverse and thrust faults, the easternmost of the thrusts being the Grechishkin overthrust zone (fig. 20). The fault planes dip northwest 20 to 35 degrees. Folds in the basin trend northeast and are sometimes overturned to the southeast. The Grechishkin overthrust zone itself is a consecutive series of reverse faults and overthrusts that override and truncate one another. Dips of the faults are generally 20 to 35 degrees but sometimes are steeper. Thus, based on the lithology of the rocks in the basin and their structural characteristics, the basin an accretionary wedge.

As previously mentioned, the Eastern Kamchatka Basin extends from southeast of Kronotsky Peninsula to north of Cape Kamchatka. From Oligocene to Middle Miocene time, the activity in this zone included continuous accumulation and deformation of the predominantly clastic suites. Orogenic activity ceased in Middle or Late Miocene time and was followed by a quiet period of Late Miocene to Pliocene sedimentation.

The period of activity of the accumulation and deformation of the rocks in the basin, an accretionary wedge, correlates with the period of activity of the Middle Tertiary Sredinny Range volcanic arc and is proposed to locate the site of the trench associated with the arc. The Middle Miocene unconformity and the following period of no tectonic activity is the result of the accretion of the Kronotsky terrane to the Eastern Ranges in Middle Miocene time. The ensuing Quaternary volcanic activity found throughout Eastern Kamchatka is the result of the development of the present day Kuril-Kamchatka subduction zone.

Figure 26 - Gravity anomaly map of Kamchatka Peninsula
(after Gnibidenko et al., 1974)

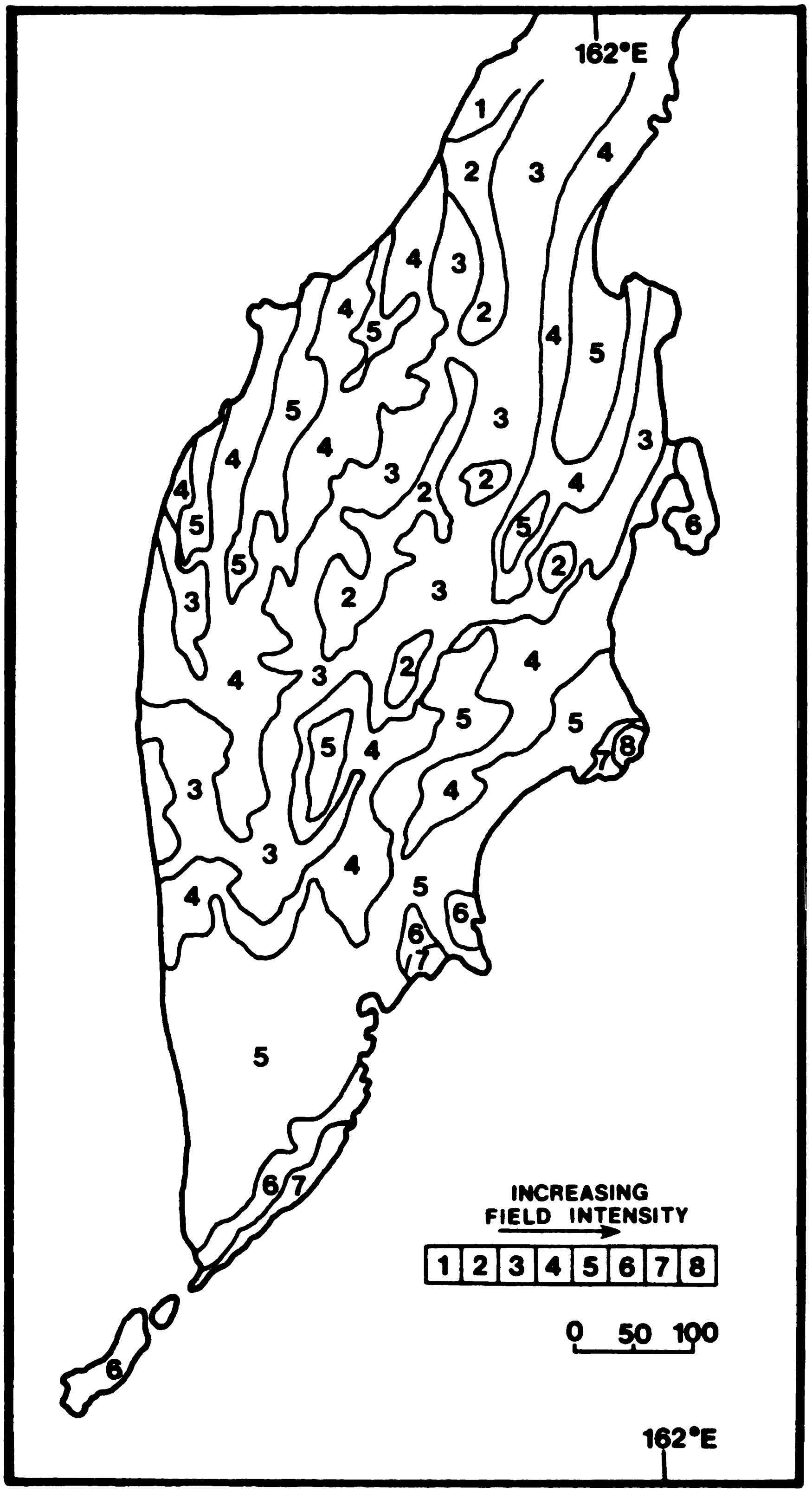


Figure 26

Figure 27 - Tectonic/geologic summary of the terranes of Kamchatka

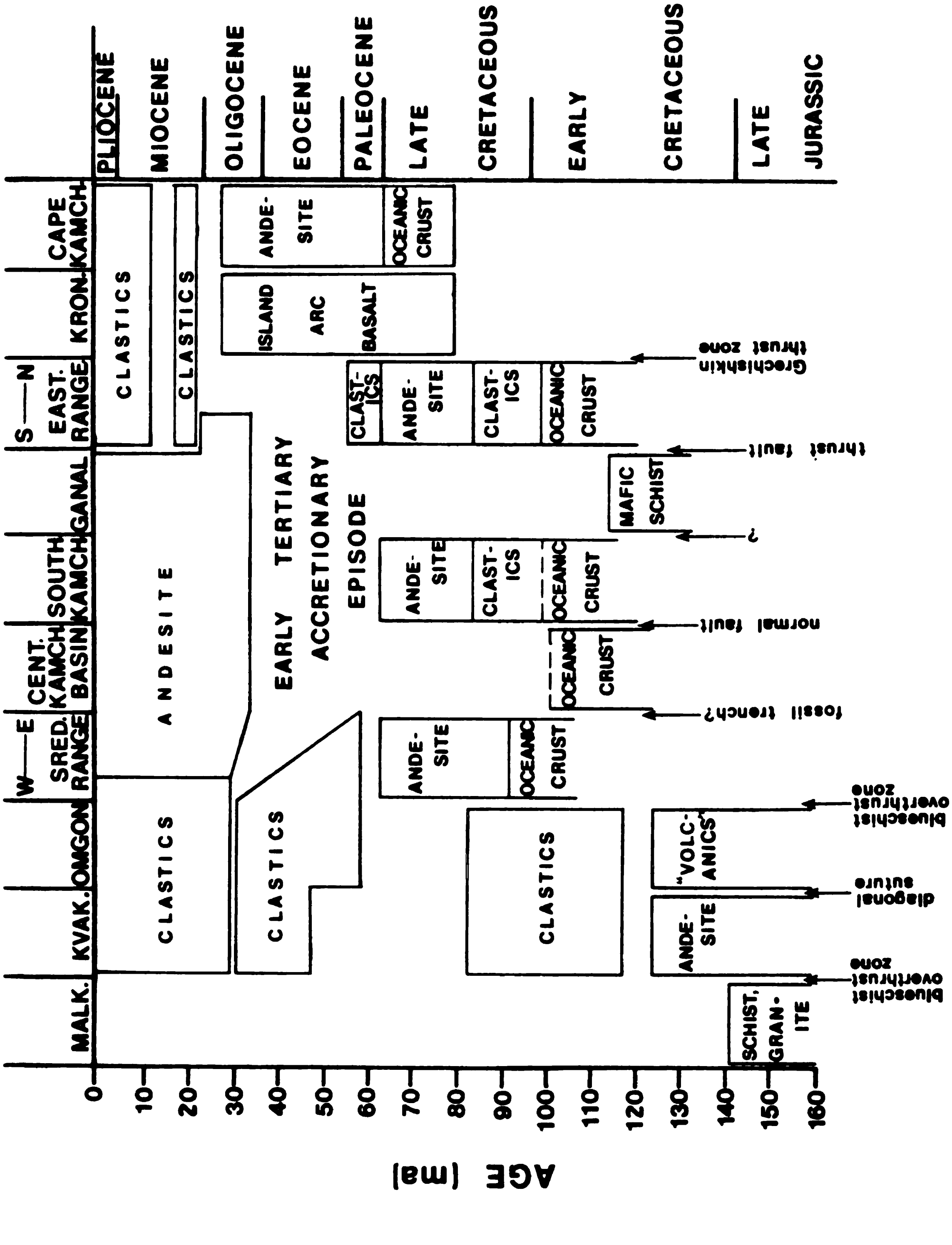

PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
PALEOCENE
LATE CRETACEOUS
EARLY CRETACEOUS
LATE JURASSIC
CAPE KAMCH.
KRON.
EAST. RANGE
S—N
GANAL
SOUTH KAMCH.
CENT. KAMCH. BASIN
SRED. RANGE
W—E
OMGON
KVAK.
MALK.
CLASTICS
ANDESITE
ANDE-SITE
OCEANIC CRUST
ISLAND ARC BASALT
CLAST-ICS
EARLY TERTIARY ACCRETIONARY EPISODE
MAFIC SCHIST
"VOLC-ANICS"
SCHIST, GRAN-ITE
Grechishkin thrust zone
thrust fault
?
normal fault
fossil trench?
blueschist overthrust zone
diagonal suture
blueschist overthrust zone
AGE (ma)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160

Figure 27

GEOLOGIC RELATIONS OF KAMCHATKA PENINSULA WITH THE KURIL AND ALEUTIAN ISLAND ARCS

Geologic data on the Kuril Island arc, extending from the southern tip of Kamchatka Peninsula, south to Hokkaido, and the Komandorskie Islands of the western Aleutian arc, located east of Cape Kamchatka, suggest these features are related tectonically to terranes of Kamchatka Peninsula.

The Kuril Islands may be divided into two separate island chains referred to as the Lesser and Greater Kuril Islands. Islands of the Lesser Kuirles are found only in the southern part of the island chain, just north of Hokkaido (fig. 3) but continues to the north as the submerged Vityaz Rise (Savostin et al., 1983; Gnibidenko et al., 1983). The stratigraphy of the islands include Late Cretaceous (Campanian) to Early Tertiary andesites, basalts, conglomerates, argillites and siltstone with layers of sandstone, Oligocene to Miocene sandstones, siltstone, argillites and volcanics and Pliocene to Quaternary andesite and basalt volcanics (Savostin et al., 1983; Markov and Khotin, 1973; Krasny, 1964). An unconformity separates the Early and Middle Tertiary rocks. Outcrops of spilite, diabase and gabbro at the base of the Late Cretaceous rocks (Krasny, 1964; Gnibidenko et al., 1983) indicates the presence of a Cretaceous oceanic layer underlying the Lesser Kuril Islands. A similar sequence of rocks is exposed in Eastern Hokkaido, the southern end of the Lesser Kurils (Kimura and Tamaki, in press). The major unconformity between early and late Paleogene rocks on Hokkaido led Kimura and Tamaki (in press) to suggest the Kula-Pacific ridge subducted there in Early Tertiary time.

No rocks older than Oligocene age are exposed in the Greater Kuril Islands. The stratigraphic column includes Late Oligocene to Early Miocene andesites, basalts, cherts, conglomerates and sandstones, Middle to Late Miocene tuffs and clastics, Pliocene tuffs, conglomerates, dacites, andesites and basalts and Quaternary basalts and andesites (Belyy, 1974; Krasny, 1964; Savostin et al., 1983; Markov and Khotin, 1973). A similar sequence is also exposed on eastern Hokkaido (Kimura and Tamaki, in press).

In general, the stratigraphy of the Kuril Islands may be correlated with geology of certain terranes of Kamchatka. The Lesser Kuriles, although not physically connected to Kamchatka, is geologically very similar to the Eastern Ranges terrane. Both regions are characterized by a period of Late Cretaceous to earliest Tertiary island arc volcanism, a Paleocene to Oligocene hiatus and Miocene to Quaternary volcanics and clastics. The period of Late Cretaceous volcanism of these regions also correlates with the period of activity of the Iruney arc, facies of which are found in the Sredinny Range terrane.

The Oligocene to Miocene formations of the Greater Kuril Islands are very similar to contemporaneous deposits found in the Sredinny Range and Southern Kamchatka terranes and suggests a continuous volcanic arc extended through central and southern Kamchatka and into the Kuril Islands during this time. From Pliocene to Quaternary time, the stratigraphy of the Greater Kuril Islands is very similar to contemporaneous formations found in the Eastern Ranges and Southern Kamchatka terranes suggesting a continuous volcanic arc extended through eastern and southern Kamchatka and into the Kuril Islands at this time.

Several authors (e.g. Markov et al., 1969; Vlasov et al., 1965) have linked Cape Kamchatka with the Komandorskie Islands of the western Aleutian Island arc. The stratigraphy of the Komandorskie Islands includes Late Paleocene to Eocene pillow basalts, pelitic and silty tuffs, tuffaceous clastics, argillite, chert, jasper and limestone, Late Oligocene to Early Miocene tuffs, andesites, basalts, tuffaceous clastics and coal, and Pliocene tuff, clastics, andesites, dacites, and basalts (Shmidt, 1978; Krasny, 1964). The basement rocks of the Early Tertiary rocks resembles the top of an oceanic layer (Shmidt, 1974). In addition, the structural trend of the islands is northwest, parallel to the trend of the Aleutian arc in this region.

The comparison of the geology of the Komandorskie Islands with Cape Kamchatka demonstrates their similarity. Both areas are characterized by a Late Cretaceous or Early Tertiary oceanic basement overlain by middle and Late Tertiary volcanic arc facies. Dating of the older formations of both terranes is tentative (Markov et al., 1969; Shmidt, 1978) but the general geologic characteristics are very similar and it is therefore possible to suggest these two areas were one continuous volcanic arc during Tertiary time that developed on oceanic crust.

Geological similarities exist between the Sredinny Range terrane and the Academy of Sciences Rise and the Lebed Swell located in the Sea of Okhotsk. Rocks dredged from these features include granite, granodiorite, andesite, rhyolite and biotite schist of middle to Late Cretaceous age as determined by K-Ar radiometric age determinations (Burk and Gnibidenko, 1977). These rocks and their ages are indicative of a Late Cretaceous island arc system that may have been continuous with the Late Cretaceous Iruney arc of the Sredinny Range terrane (Savostin et al., 1983).

PLATE MOTIONS

The relationship between tectonic events, such as island arc andesitic volcanism, orogenic uplift, ophiolite emplacement, etc., and the characteristics of motion of oceanic crustal plates, i.e., direction and velocity, that determine angles of convergence between the oceanic plates and a particular region, has been demonstrated for many areas in the Circum-Pacific region (e.g., Wallace and Engebretson, 1984; Engebretson et al., 1984; Henderson et al., 1984; Page and Engebretson, 1984; and others). Comparison of the postulated tectonic events of Kamchatka Peninsula with plate motion data from Engebretson (1982) indicates several tentative relationships. Examination of the location of the plate boundaries (figs. 29 through 34) with respect to the relative motion of the plates (fig. 28) since the end of the Jurassic period, the approximate time of the initiation and development of the terranes of Kamchatka, indicate that the Izanagi, Farallon, Kula and Pacific plates interacted with Kamchatka during Cretaceous and Tertiary time. Specifically, the relative motion vector data were determined at 165° E longitude, 65° N latitude, located north of Kamchatka in northeast Siberia. Due to the proximity of this point with Kamchatka, it will be assumed that the relative motion data are valid also for the region of Kamchatka Peninsula.

Four different oceanic plates interacted with the region of Kamchatka Peninsula during Mesozoic and Cenozoic

Figure 28 - Plate motion data of the Farallon, Izanagi, Kula and Pacific plates showing direction only. Shoreline of Kamchatka parallels the north arrow (from Engebretson, 1982)

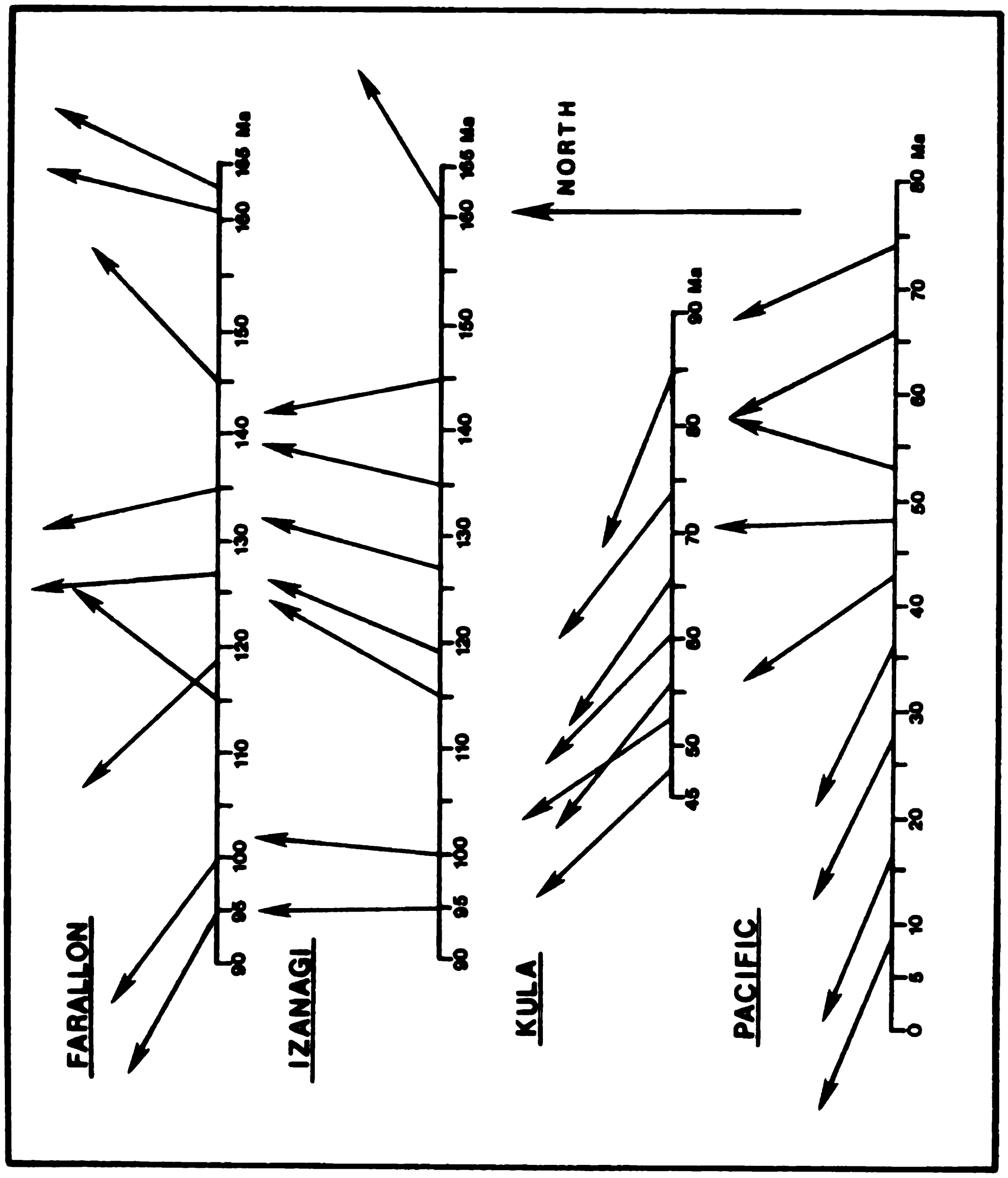

FARALLON
IZANAGI
KULA
PACIFIC
NORTH
90 95 100 110 120 130 140 150 160 165 Ma
90 95 100 110 120 130 140 150 160 165 Ma
45 50 60 70 80 90 Ma
0 5 10 20 30 40 50 60 70 80 Ma

Figure 28

time. They are, in order of appearance, the Farallon, Izanagi, Kula and Pacific plates. There are five different time periods during which these plates may have interacted with Kamchatka (table 4). During three of the time periods, interaction between Kamchatka and a single plate occurred while during two transitional periods, both ending with major plate reorganizations, it is difficult to determine which of two plates interacted with Kamchatka due to a lack of data on the location of plate boundaries during these time periods.

The direction of motion of the four oceanic plates with respect to Kamchatka since the beginning of the Late Jurassic (fig. 28) and the characteristics of the major plate reorganizations are as follows. From 165 to 115 Ma, the Farallon plate was located in the vicinity of Kamchatka. At the beginning of this period, the plate was moving generally northeast with respect to Kamchatka but from 145 to 135 Ma, the direction of motion changed from N46°E to N348°E, a more north-northwest direction. A northwesterly direction of motion was maintained through 119 Ma, the direction at 127 Ma being N355°E and at 119 Ma, N317°E. From 119 to 115 Ma, the direction changed from northwest to N37°E, northeast, and from 115 to 100 Ma, the direction changed back to N307°E, northwest.

Around 100 Ma, the Farallon/Izanagi ridge passed through the vicinity of Kamchatka and interaction of the Farallon plate with Kamchatka ceased and interaction

Table 4 - Correlations between tectonic events of Kamchatka Peninsula and relative motions of oceanic plates

Table 4

Age (Ma)	Tectonic Event	Terrane(s)	Time Period
0–5	East. Ranges, S. Kamch. arc	Eastern Ranges, S. Kamchatka	5 Ma to pres.
8–30	Sredinny Range / S. Kamchatka arc	Sredinny Range, Ganal, Eastern Ranges, Southern Kamchatka	30 to 8 Ma; Late Oligocene to Late Miocene
35–55	Cape Kamchat. volcanic act.	Cape Kamchatka	55 to 35 Ma, Paleocene to Miocene
	unconformity elsewhere	All terranes except Kronot., C. Kamchatka	
60–85	Truncy and E. Ranges volcanic arcs	Sredinny Range, Eastern Ranges	85 to 60 Ma, Santonian to Early Paleocene
88–110	Clastic sedimentation, no volcanic activity	Kvakhon, Omgon	110 to 88 Ma, Aptian to Turonian
115–165	Kvakhon / Omgon volcanic arc	Kvakhon / Omgon (Malkinsk ?)	165 to 115 Ma, Late Jurassic to Early Cretaceous

Age (Ma)	Oceanic Plate	Direction of Motion	Time Period
0–43	Pacific Plate	Northwest, N293°E to N325°E	43 Ma to present, Eocene to Quaternary
45–66	Pacific Plate ? Kula Plate ?	NNE, N17°E to N357°E NW, N309°E to N325°E	66 to 45 Ma, earliest Tertiary to Eocene
66–87	Kula Plate	Northwest, N292°E to N316°E	87 to 66 Ma, Coniacian to latest Cretaceous
90–110	Izanagi Plate ?	North-Northeast, N30°E to N359°E	110 to 90 Ma, Albian to Turonian
120–140	Farallon Plate	North-Northwest, N316°E to N37°E	140 to 120 Ma, Early Cretaceous
140–170	Farallon Plate	Northeast, N47°E	Jurassic to Early Cretaceous

between the Izanagi plate and Kamchatka commenced. The exact time of the event cannot be determined without a more precise estimate of location of the Farallon/Izanagi ridge and of the location of the middle Cretaceous Kamchatka Peninsula. Because of this uncertainty, the motion vector data for the Izanagi plate will be presented starting at 115 Ma, overlapping the Farallon motion vector data to allow for the error in the location of the two regions. Generally, the Izanagi plate moved north with respect to northeast Siberia with the plate motion being N30°E at 115 Ma, N6°E at 100 Ma and N359°E at 95 Ma. From 165 to 95 Ma, it is possible that a triple junction existed where the Izanagi/Farallon ridge intersected the Eurasian coastline. The motion data suggest convergence between the Farallon plate and Eurasia occurred north of the triple junction while transcurrent motion between the Izanagi plate and Eurasia occurred south of the triple junction. In addition, the position of the point, as indicated by the position of the Izanagi/Farallon ridge crest, would have been far south of northeast Siberia in Jurassic time but migrated north in Jurassic and Early Cretaceous time.

Around 90 Ma, the first major plate reorganization occurred. The Izanagi/Farallon ridge, trending approximately north/south at this time, ceased spreading. A new spreading center, the Kula/Farallon ridge, formed in the eastern region of the Pacific Basin, adjacent to North America. The reorganization split the Farallon plate into two parts, with the southern portion remaining as the Farallon plate and the northern half, in addition to the entire Izanagi plate, becoming an enlarged Kula plate. The Kula plate thus extended across the northern half of the basin while the Pacific plate occupied the southwestern area and the Farallon plate occupied the southeastern area of the basin. The reorganization changed the direction of motion of the Kula plate, which was the Izanagi plate, to a more northwesterly direction. At 85 Ma, the Kula plate was moving N293°E, to the northwest. Very consistent northwesterly convergence continued through 48Ma, ranging from N307°E to N325°E

Around 60 Ma, the Kula/Pacific spreading center entered into the vicinity of the Early Tertiary Kamchatka Peninsula. From 66 to 53 Ma, the direction of motion of the Pacific plate changed from N333°E to N17°E and from 53 to 48 Ma, changed direction of motion to N357°E. During this time period, from around 60 to 45 Ma, it is difficult to determine which plate interacted with Kamchatka due to imprecise knowledge of the location of the Kula/Pacific spreading ridge and the location of Early Tertiary Kamchatka Peninsula.

The second major plate reorganization occurred around 45 Ma and involved the cessation of activity of the Kula/ Pacific ridge and the formation of an enlarged Pacific plate that included the unsubducted remainder of the Kula plate. The Pacific plate thus occupied the western and central regions of the basin while the Farallon plate was located only along the North and South American coasts. The Pacific/Farallon ridge trended north/south. The reorganization was accompanied by a major change in the direction of motion of the Pacific plate, from N357°E at 48 Ma to N325°E at 43 Ma. The change in motion from north to northwest is indicated by the change in the trend of the Hawaiian/Emperor seamount chain. Northwesterly motion of the Pacific plate has continued from 43 Ma to the present, with the direction consistently ranging from N293°E to N305°E.

A correlation can be made between the periods of northwesterly motion of the oceanic plates, corresponding to convergence towards northeastern Siberia and Kamchatka Peninsula, and periods of volcanic arc activity on Kamchatka. Periods of no volcanic activity on Kamchatka may either be related to no subduction activity, i.e., a passive, transcurrent margin separating Kamchatka and the oceanic plate, or to the subduction of a ridge crest. Ridge crest subduction has been suggested to reduce or completely eliminate volcanic arc activity in the Kuril Islands in Early Tertiary time (Kimura and Tamaki, in press) and in the Aleutian Islands in Middle Tertiary time (Delong et al., 1978). These periods are also accompanied by uplift and erosion.

The Kvakhon/Omgon arc is proposed to have originated in response to a shift in the direction of motion of the

Farallon plate around 165 Ma, the beginning of the Late Jurassic epoch. The proposal is based on the fact that the Farallon plate was in the vicinity of northeast Siberia at this time and would have been responsible for any volcanic arc activity in the region. Convergence towards northeast Siberia persisted until around 110 Ma, when the Farallon/Izanagi ridge passed through the vicinity of Kamchatka causing interaction of the Farallon plate with Kamchatka to cease and interaction of the Izanagi plate with Kamchatka to begin. This period was one of transcurrent motion between the Izanagi plate and Kamchatka, an idea based on the northerly direction of motion of the Izanagi plate, the lack of volcanics of middle Cretaceous age on Kamchatka and the period of middle Cretaceous sedimentation. Around 90 Ma, convergence between the reorganized Kula plate and Kamchatka began and resulted in the formation of the Iruney arc of the Sredinny Range terrane and the Eastern ranges arc of the Eastern Ranges terrane. The two arcs may have formed along transform faults found on the former Izanagi plate that trended in a general north-south direction. The fracture zones provided zones of weakness along which convergent margins could form (Hilde et al., 1977) and led to a situation that is similar to the present day Phillippine Sea arc system.

Northwesterly motion of the Kula plate continued through Paleocene and Eocene time. However, volcanism of the Iruney and Khapitsk arcs had ceased by the beginning of Paleocene time and was replaced by a period of uplift and erosion, as evidenced by an unconformity of that age found on all terranes of Kamchatka except the Omgon and westernmost Sredinny Range terranes. In contrast, volcanic arc facies of the Cape Kamchatka and Kronotsky terranes are of Paleocene to Oligocene age and suggest convergent/ subduction activity commenced in the Early Tertiary. Plate motion vector data suggest a scenario during this time that differs from previous ideas. The Kula plate during this time continued moving in a northwesterly direction of convergence towards Kamchatka Peninsula. In contrast, the Pacific plate at the beginning of this time interval changed direction of motion from northwesterly to north-northeast, and continued this direction of motion until around 43 Ma. It is therefore possible that the Kula plate did not extend as far west as Kamchatka in Early Tertiary time and that the Pacific plate was located off the coast of Kamchatka and did interact with the western Aleutian Island arc, specifically, the Cape Kamchatka terrane and the Komandorskie Islands. In this scenario, transcurrent motion between the Pacific plate and the Eastern Ranges occurred while underthrusting of the western Aleutian arc occurred. This explains the lack of volcanic material of any composition of this age throughout Kamchatka except for the Cape Kamchatka terrane.

Alternatively, subduction of the Kula/Pacific ridge crest in the Kuril Island arc system is suggested to have occurred in Paleocene and Eocene time as evidenced by the lack of magmatic activity of the arc and the period of uplift and erosion (Kimura and Tamaki, in press). The characteristics of no magmatism, uplift and erosion also pertain to all of Kamchatka Peninsula except the Omgon, Cape Kamchatka and westernmost Sredinny Range terranes. In either case, it is difficult to reconcile these two events occurring simultaneously, the Paleocene/Eocene unconformity resulting from northwestward directed convergence of the Kula plate and ridge subduction, and the development of the western Aleutians, including Cape Kamchatka, in response to northward directed convergence of the Pacific plate. Most likely the presence of the ridge crest in the vicinity of a subduction zone in conjunction with the small portion of unsubducted plate remaining in Early Tertiary time led to a complex oceanic plate/subduction zone interaction in which forces other than those indicated by the plate motion vector data were present. In addition, the presence of other plates not accounted for in the plate motion vector data in the vicinity of the northwest Pacific Basin at this time would also complicate the situation.

By Late Eocene time, the second major plate reorganization had occurred and the Kula plate had become part of the Pacific plate due to the demise of the Kula/Pacific spreading center. From 43Ma (Late Eocene) to the present, the Pacific plate moved in a northwesterly direction and converged towards Kamchatka. The northwest motion of the Pacific plate led to the eruption of the volcanics of the Sredinny Range and the Greater Kuriles volcanic arcs. An accretionary event in Middle Miocene time shifted the axis of the volcanism to the present day Kuril-Kamchatka volcanic arc.

TECTONIC EVOLUTION OF KAMCHATKA PENINSULA

The tectonic evolution of Kamchatka Peninsula occurred during Mesozoic and Cenozoic time, as inferred from the ages of rocks of the peninsula, and was controlled by the direction of motion of oceanic plates in the Pacific Basin during the same time interval.

The oceanic plate configuration at the beginning of the Late Jurassic period (165 Ma) consisted of two plates, the Farallon plate, moving in a northeasterly direction and occupying approximately the northern half of the Pacific Basin, the vicinity of northeastern Siberia, and the Izanagi plate, moving north and occupying the southwestern portion of the Pacific Basin (fig. 29a). By 165 Ma, direction of motion of the Farallon plate altered in such a way as to initiate the subduction activity responsible for the development of the Kvakhon/Omgon volcanic arc (fig. 29a), a correlation based on the similarities in timing of the position of the Farallon plate and the paleontological age dates obtained from volcanic arc facies of the Kvakhon terrane. This age also correlates well with the abundant Jurassic volcanic arc rocks found along the extent of the Japanese Islands (Taira et al., 1983) indicating subduction zone activity commenced in the Jurassic along a large portion of the eastern Asiatic coast.

During the period of activity of the Kvakhon/Omgon arc, from Late Jurassic to Early Cretaceous, the Farallon/ Izanagi ridge rotated in a clockwise direction and swept along the eastern coast of Eurasia (figs. 29a, b, and c). The Farallon plate continued convergence towards the region of northeastern Siberia and the Izanagi plate continued moving in a north to northeasterly direction relative to Kamchatka. This scenario allows for the possibility of a ridge-trench-transform triple junction that existed during this time at the intersection of the Farallon/Izanagi ridge with the Eurasian coast (figs. 29a and b). Transcurrent motion between the Izanagi plate and Eurasia occurred south of the triple junction and convergent activity between the Farallon plate and Eurasia occurred north of the triple junction. The location of the triple junction migrated north along the Eurasian coast as the Izanagi/Farallon ridge rotated clockwise in the Pacific Basin.

The origin of the Malkinsk terrane and the reason for its present location may be explained by the motion of the oceanic plates and the presence of the triple junction. The oldest ages of the granitic plutons of the terrane are Jurassic and, taking into account their probable genetic origin, indicates they originated during a Jurassic period of subduction related plutonism, possibly in response to underthrusting of the Farallon plate. The original position of the terrane is unknown. The period of transcurrent motion between Eurasia and the Izanagi plate is proposed to have dislocated fragments of the Eurasian margin onto the northward moving plate, including the Malkinsk terrane, after passage of the triple junction to

Figure 29 - Late Jurassic to Late Cretaceous tectonic evolution of Kamchatka Peninsula

a. Late Jurassic to Early Cretaceous

b. Hauterivian to Aptian

c. Albian

d. Cenomanian

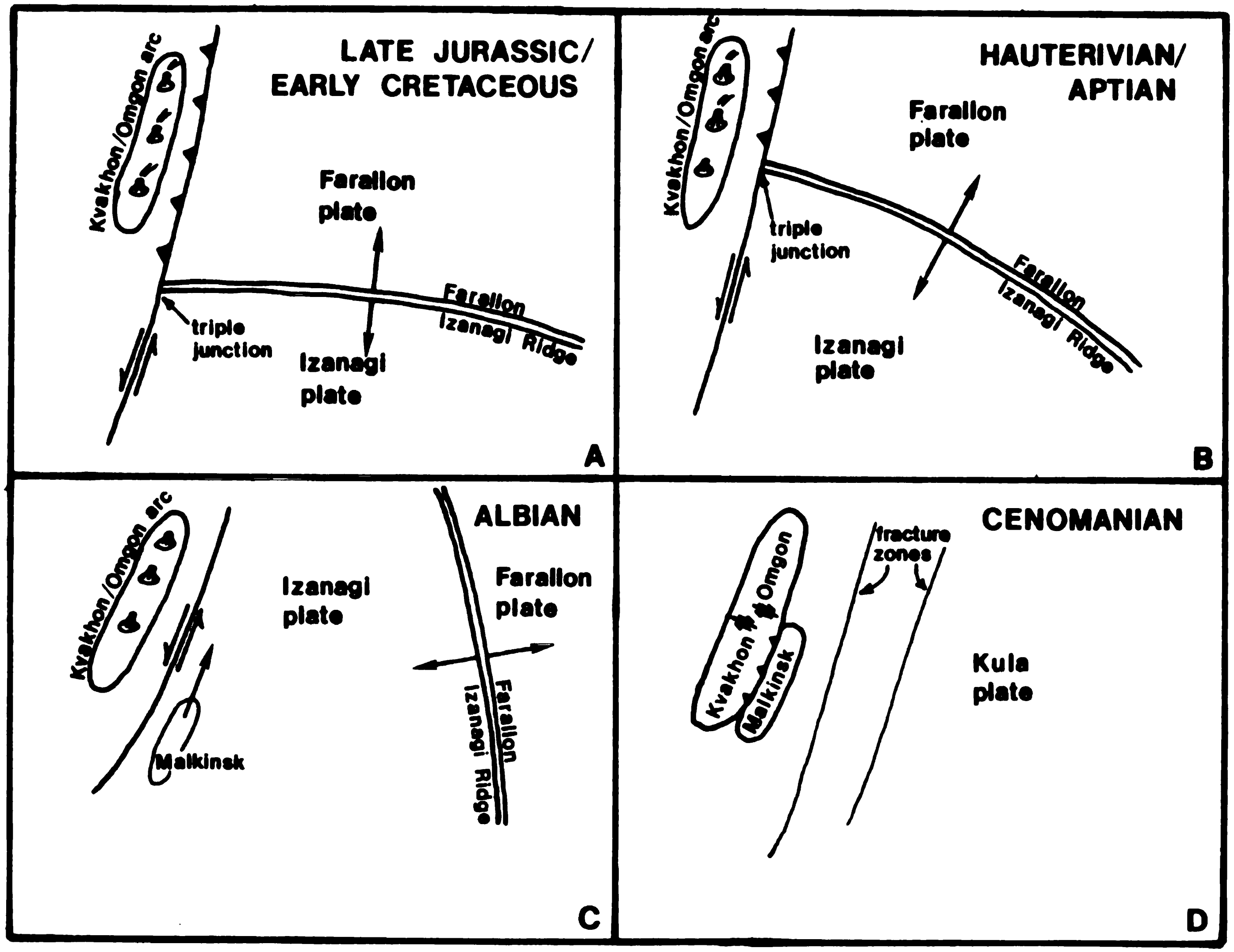


Figure 29 a, b, c and d

the north of the original location of the terrane (fig. 29b). Evidence favoring the idea is again found in Japan, where Paleozoic and Mesozoic terranes have been emplaced as a result of transcurrent plate motions and oblique subduction (Taira et al., 1983). Some of the crustal fragments in Japan are Devonian in age, corresponding to the age of the spore assemblage found in the Malkinsk terrane. In addition, Devonian aged rocks are also reported from the Ust-Belaya ophiolite complex of the Koryak Highlands and in northwestern Kamchatka (Fujita and Newberry, 1983). The possibility therefore exists that Devonian through Jurassic crustal fragments or blocks have been rafted northward along the Mesozoic Asiatic margin in a manner similar to what is observed in certain western North American terranes, e.g., Wrangellia (Jones et al., 1977), which led to the emplacement of Devonian blocks along the Japanese and Siberian coast into Jurassic to Early Cretaceous subduction zones.

Volcanic activity of the Kvakhon/Omgon arc is estimated to have lasted until 115 Ma, Aptian (middle Cretaceous time), the approximate time of change of direction of motion of the Farallon plate from the northwest to northeast. The lack of subduction related volcanic activity on Kamchatka is indicated by Albian clastic sediments found in several localities of the Omgon terrane and by "middle Cretaceous" sediments found on the Kvakhon terrane. Contemporaneously, the Malkinsk block was being rafted northward on the Izanagi plate.

By 100 Ma, the Farallon plate had changed direction of motion relative to northeast Siberia back to convergent, i.e., to the northwest, and continued motion in such a manner until around 90 Ma, the time of the first major plate reorganization of the Pacific Basin oceanic plates. In contrast, the Izanagi plate continued north to northeasterly motion relative to Northeast Siberia from 115 Ma up to around 90 Ma. Based on the character of the northward migrating triple junction and the lack of Albian to Turonian volcanic rocks anywhere on Kmchatka, it may be suggested that between 115 and 100Ma, the junction had passed the vicinity of Kamchatka Peninsula, an event that would mark the end of Farallon/Kamchatka interaction and the beginning of transcurrent Izanagi/Kamchatka interaction (fig. 29c). A related event of importance is the development of the Okhotsk-Chukotka volcanic arc in Aptian time (around 116 Ma) and the duration of activity of the arc, until Maastrichtian (around 70 Ma) time (Fujita and Newberry, 1983). The arc rocks indicate a period of middle to Late Cretaceous convergence, a time that coincides with a period of only clastic sedimentation on the Kvakhon and Omgon terranes of Kamchatka. Why arc volcanism did not occur on these terranes at this time may be due to the previously suggested period of transcurrent motion between Kamchatka and the Izanagi plate. An interesting alternative is that the Kvakhon/Omgon arc was not located in its present position with respect to northeastern Siberia, and may have been located to the south, away from the convergent activity taking place to the north. Later attachment of the arc to a northward moving plate brought the arc to its present location.

One accretionary event of importance occurred during this period of uncertain plate motions. The Malkinsk terrane and the Kvakhon/Omgon arc, presumably juxtaposed due to the northward motion of the Izanagi plate, accreted in Albian or Cenomanian time (fig. 29d). The event thrust the southern part of the arc over the Malkinsk terrane and divided the arc into the Kvakhon and Omgon terranes. The "Diagonal geosuture", the boundary between the terranes, may have originated at this time due to obduction of only the southern part of the arc. The timing of this event is dated by radiometric age dates from metamorphic rocks of the Kolpakova series of the Malkinsk terrane that average 97 Ma (early Cenomanian), the middle Cretaceous unconformity of the Kvakhon terrane and the Cenomanian unconformity of the Omgon terrane. In addition, the deposition of the clastic Lesnovo series, a northeastern extension of the Omgon series found in the Omgon terrane, occurred at this time in response to the uplift and erosion of the southwestern portion of the Omgon terrane. The source terrane of both the Omgon and Lesnovo series is suggested to have been the Kvakhon/Omgon arc and/or the Malkinsk block.

Around 90 Ma, the reorganization that included the cessation of spreading of the Izanagi/Farallon spreading center and drastic changes in direction of motion of the Kula plate, occurred. Northwesterly directed convergence between northeast Siberia and the Kula plate commenced and by 85 Ma, Santonian time, the volcanic arc activity of the Iruney and Eastern Ranges arcs had commenced (fig. 30). The arcs are may have formed along fracture zones located on the Izanagi plate (fig. 29d) prior to the plate reorganization episode.

Formation of the two arcs entrapped a fragment of oceanic crust between them, presumably a portion of the Izanagi plate, and marks the initial stage of development of the Central Kamchatka Basin (fig. 30). The Late Cretaceous arc system extended through the Sredinny Range and Eastern Ranges terranes, through the Southern Kamchatka terrane and into the Sea of Okhotsk, where Late Cretaceous arc rocks are found on the Lesser Kuril Islands and on the Academy of Sciences Rise.

The trench of each of the arcs is proposed to have been located along their eastern margins based on the predominance westward subducting active margins along the western Pacific today. Specifically, the trench of the Iruney arc may be identified as the narrow, elongate, geophysically identified trough found along the western edge of the Central Kamchatka Basin. No particular geological or geophysical feature may be related to the

Figure 30 - Santonian to Maastrichtian tectonic evolution of Kamchatka Peninsula

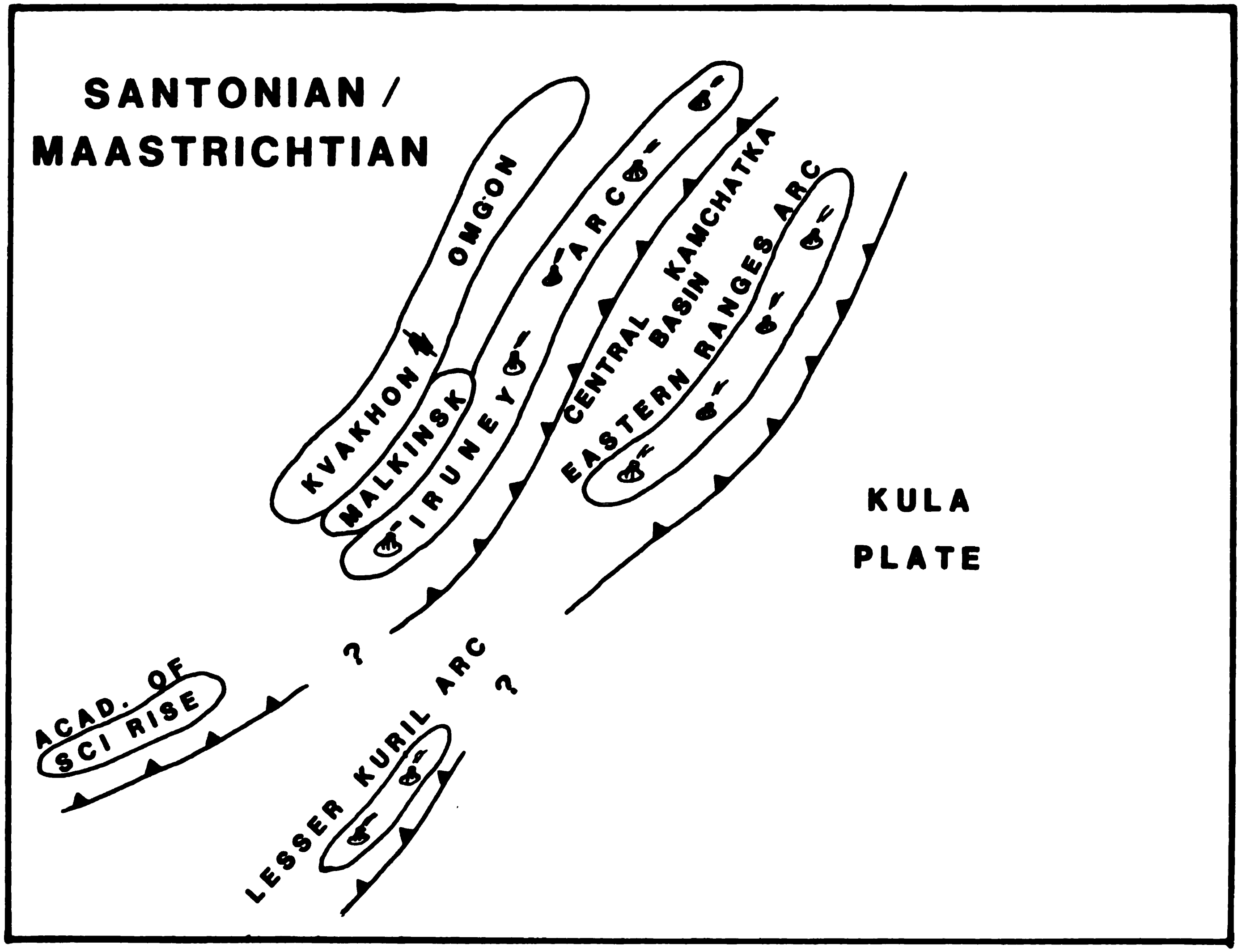

SANTONIAN / MAASTRICHTIAN
OMGON
KVAKHON
MALKINSK
IRUNEY ARC
CENTRAL KAMCHATKA BASIN
EASTERN RANGES ARC
KULA PLATE
ACAD. OF SCI RISE
LESSER KURIL ARC
?
?

Figure 30

trench associated with the Eastern Ranges arc but it was probably to the east of the arc.

During the period of activity of the Iruney and Eastern Ranges arcs, the parent material of the Ganal terrane, a fragment of oceanic lithosphere, moved into the vicinity of Kamchatka. A major Early Tertiary accretionary event (fig. 31) deformed and sheared the rocks into the epidote-amphibolite metamorphic facies of the Ganal series. The accretionary episode involved the amalgamation of the Eastern Ranges arc and the Ganal terrane to western Kamchatka, the thrusting of the allochthonous Iruney arc facies over the eastern margin of the Malkinsk terrane, and the compression and metamorphism of the Khavyven uplift, a portion of the oceanic basement of the Central Kamchatka Basin. The accretionary event may be attributed to the collision of the Eastern Ranges arc to the Iruney arc, an event that occurred when most or all of the oceanic crust of the Central Kamchatka Basin had subducted under the Iruney arc, thus closing the gap between the two arcs. Continued northwesterly directed compressional stresses of the Kula plate after the arcs juxtaposed were responsible for the majority of the thrusting and metamorphic activity. Deformation and metamorphism of the parent rocks of the Ganal terrane occurred when a wedge of oceanic lithosphere became entrapped between the accreting arcs and was subjected to high pressure and temperature conditions. The zone of shearing extended to the Avacha Inlet.

Figure 31 - Early Paleocene tectonic evolution of Kamchatka Peninsula

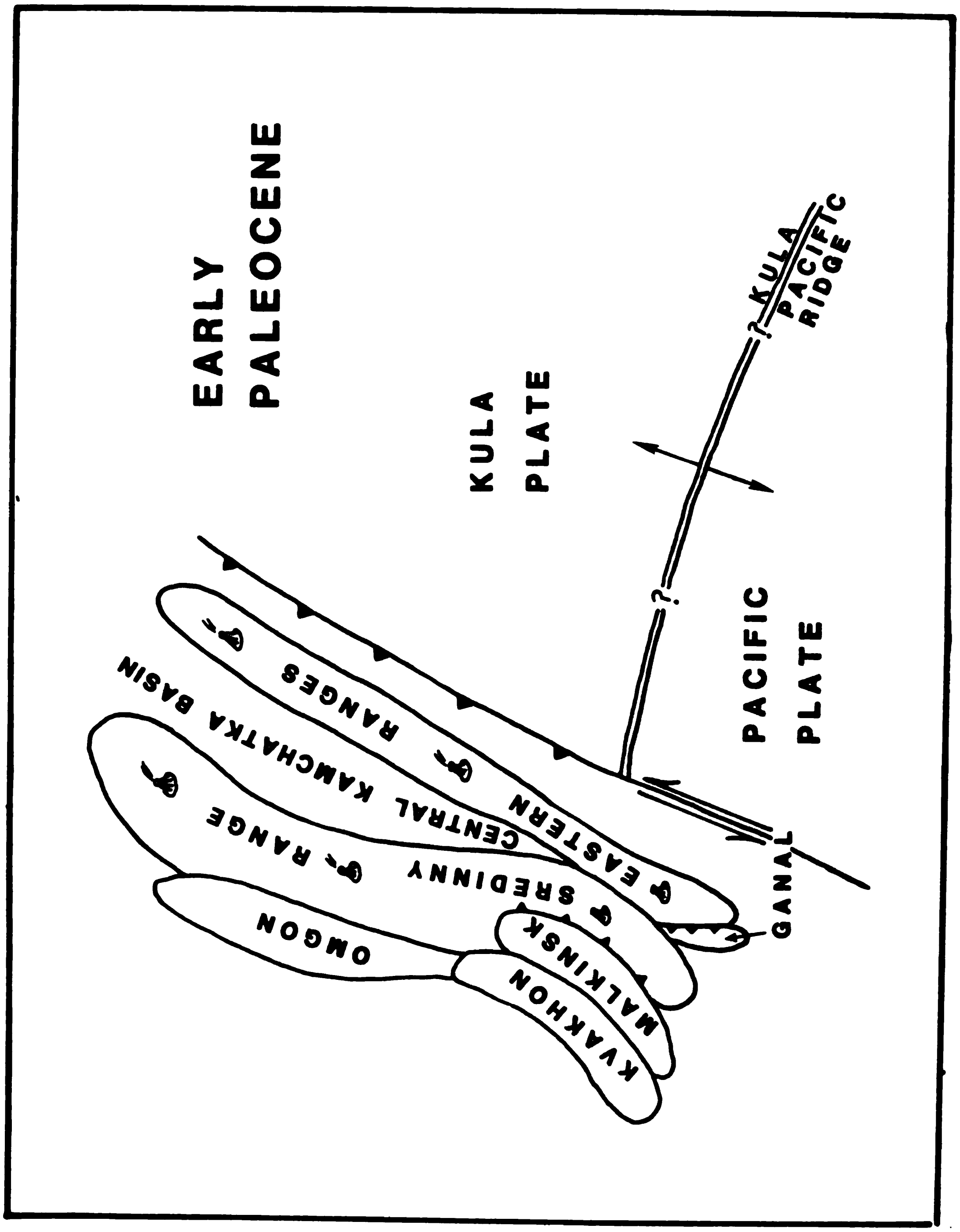

EARLY PALEOCENE
KULA PLATE
PACIFIC PLATE
KULA PACIFIC RIDGE
?
?
EASTERN RANGES
CENTRAL KAMCHATKA BASIN
SREDINNY RANGE
OMGON
MALKINSK
KVAKHON
GANAL

Figure 31

Volcanic arc activity also ceased at the time of the accretionary event, in Early Paleocene time, as evidenced by the ensuing Paleocene to Oligocene period of uplift and erosion devoid of the deposition of either clastic or volcanic facies.

Two possibilities exist for which plate interacted with Kamchatka during the Early Tertiary. Either the Kula plate, moving northwesterly with respect to northeast Siberia or the Pacific plate, moving northerly with respect to northeast Siberia, may have been located oceanward of Kamchatka, although most likely a more complex plate system occurred. The geology of Kamchatka in the Early Tertiary consists of only minor clastic deposition and volcanic activity and suggests either a Kula-Pacific ridge subduction event, also suggested to have occurred in the Kuril Islands during the same time interval (fig. 32a) (Kimura and Tamaki, in press) or transcurrent motion between Kamchatka and the Pacific plate (fig. 32b). The presence of a northward migrating Kula/Pacific ridge in this region of the Pacific Basin is uncertain as are the oceanic plate boundaries at this time (Engebretson, 1982). Two events that tend to support an interaction between a northerly moving Pacific plate and Kamchatka are the volcanic activity of the western Aleutian arc, including the Komandorskie Islands and Cape Kamchatka, that commenced in Paleocene or Eocene time and the emplacement of the Olyutorsk terrane of the Koryak Highlands sometime

Figure 32a - Paleocene to Eocene tectonic evolution of Kamchatka Peninsula with subduction of the Kula/Pacific ridge

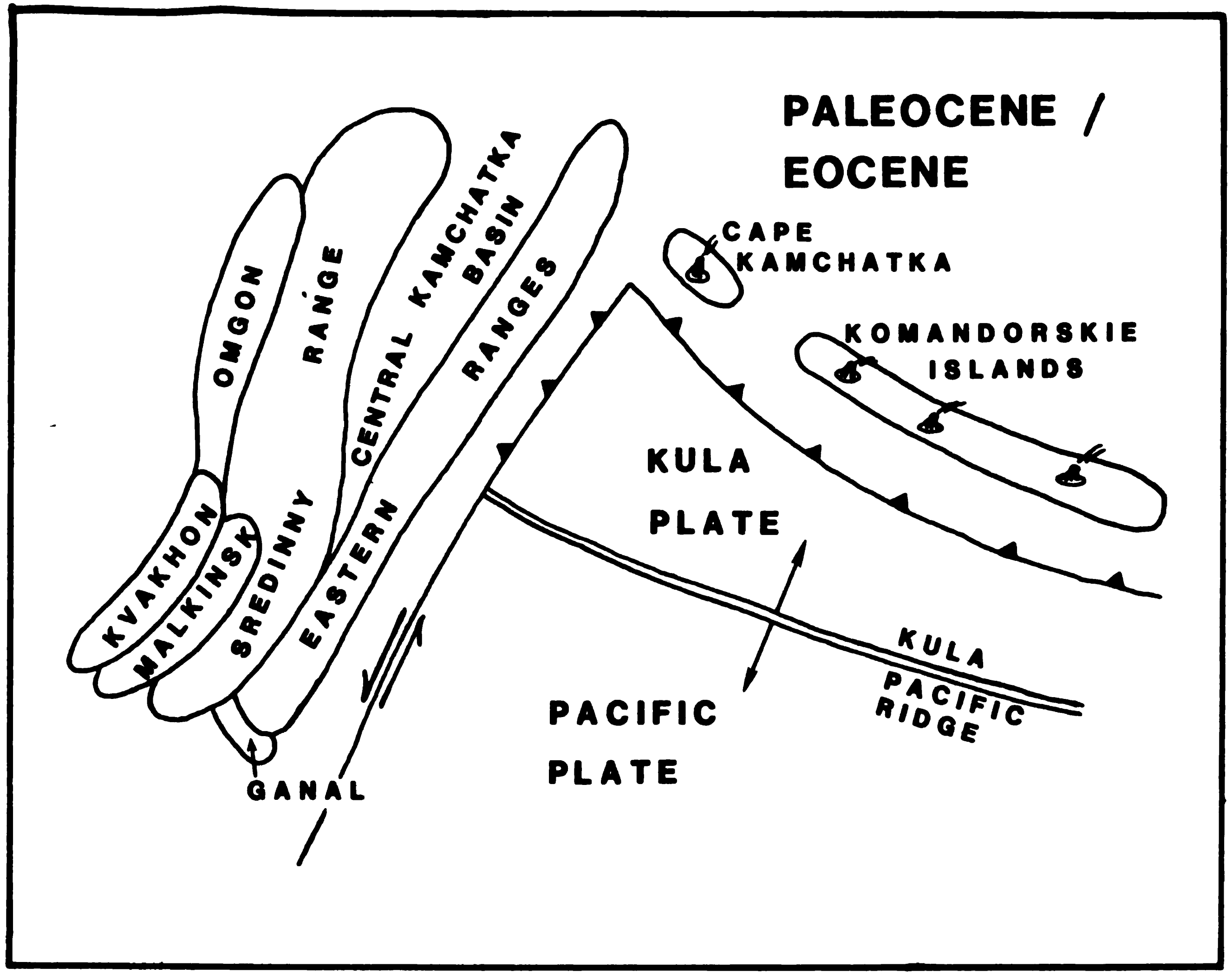

PALEOCENE / EOCENE
CAPE KAMCHATKA
KOMANDORSKIE ISLANDS
KULA PLATE
KULA PACIFIC RIDGE
PACIFIC PLATE
OMGON
RANGE
CENTRAL KAMCHATKA BASIN
RANGES
KVAKHON
MALKINSK
SREDINNY
EASTERN
GANAL

Figure 32a

Figure 32b - Paleocene to Eocene tectonic evolution of Kamchatka with transcurrent motion between the Pacific plate and Kamchatka

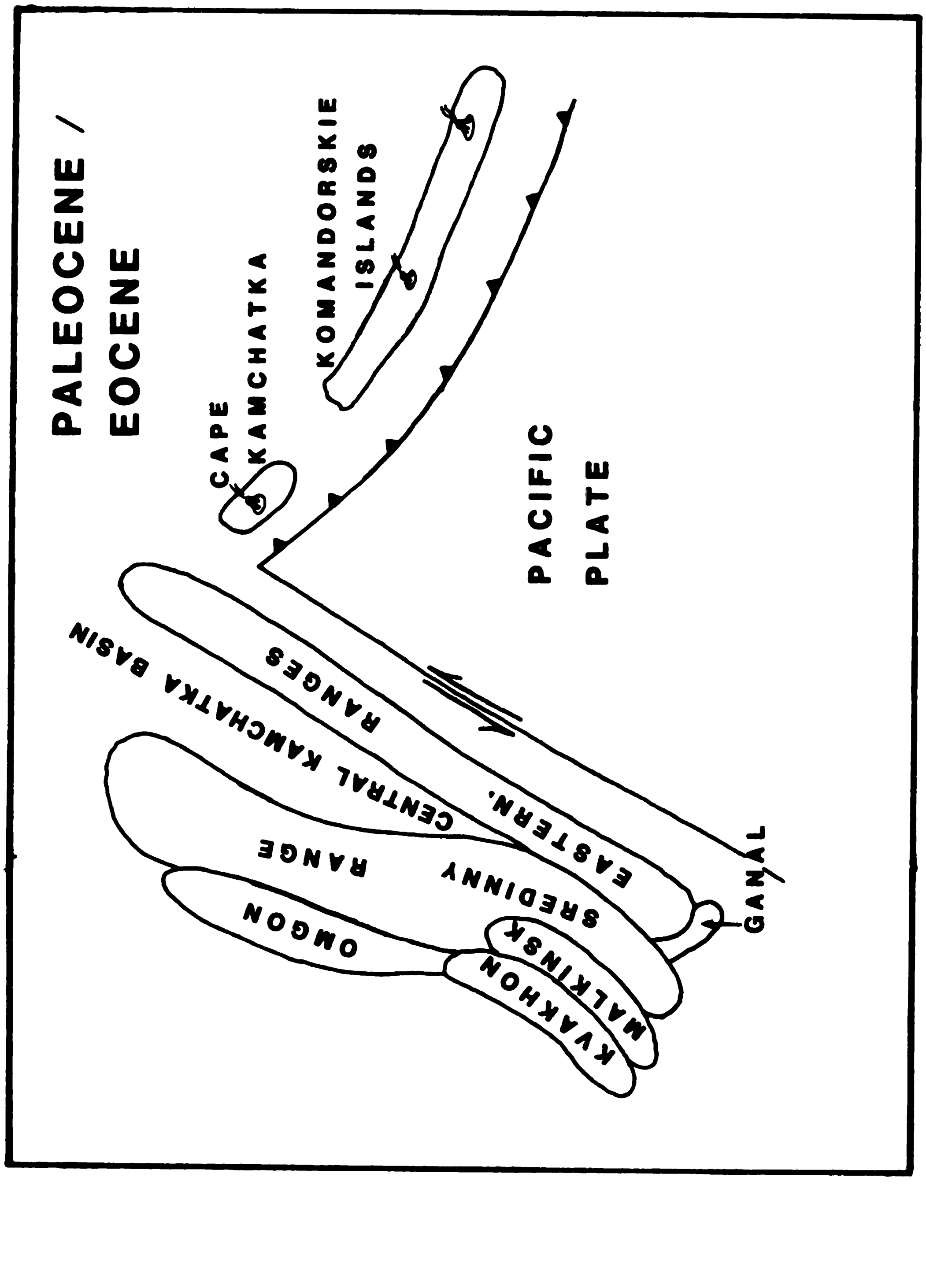

PALEOCENE / EOCENE
CAPE KAMCHATKA
KOMANDORSKIE ISLANDS
PACIFIC PLATE
CENTRAL KAMCHATKA BASIN
EASTERN, RANGES
SREDINNY RANGE
OMGON
MALKINSK
KVAKHON
GANAL

Figure 32b

in the same time interval (Fujita and Newberry, 1983). Both these events, assuming the current spatial relationships were also present in the Early Tertiary, could be the result of northerly motion of the Pacific plate.

In Eocene time, the second major plate reorganization occurred that included the demise of the Kula/Pacific ridge and the formation of a larger Pacific plate due to the removal of the boundary separating the Kula and Pacific plates. Following the reorganization, the Pacific plate occupied the most of the Pacific Basin and moved in a northwesterly direction of convergence with respect to northeast Siberia. Portions of the Farallon plate continued to exist but only along the western coasts of North and South America.

The initiation of convergence between northeast Siberia and the Pacific plate after the reorganization led to the development of the Oligocene to Miocene Sredinny Range and Greater Kuril volcanic arc (fig. 33). The trench associated with the arc in the Kamchatka region was located at the site of the present day Eastern Kamchatka Basin, indicated by the presence of an accretionary wedge, and continued south to connect with the Kuril trench off the coast of the Southern Kamchatka terrane.

In the Greater Kuril Islands and the Southern Kamchatka terrane, volcanism continued until Quaternary time without change. However, in Kamchatka the axis of volcanic

Figure 33 - Oligocene to Miocene tectonic evolution of Kamchatka Peninsula

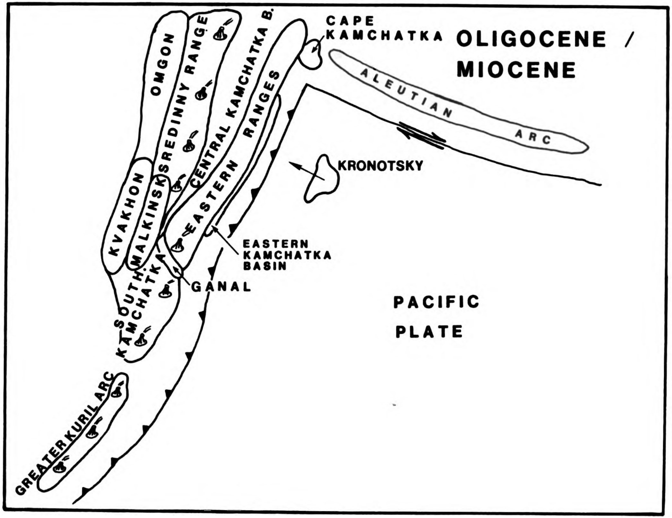

OLIGOCENE /
MIOCENE
CAPE
KAMCHATKA
ALEUTIAN
ARC
KRONOTSKY
OMGON
SREDINNY RANGE
CENTRAL KAMCHATKA B.
EASTERN
RANGES
KVAKHON
MALKINSK
SOUTH
KAMCHATKA
GANAL
EASTERN
KAMCHATKA
BASIN
PACIFIC
PLATE
GREATER KURIL ARC

Figure 33

activity changed in Pliocene time to the current observed volcanic activity in the Eastern Ranges. The shift in the axis of volcanism towards the Pacific Ocean was related to the accretion of the Kronotsky terrane to Eastern Kamchatka in Middle Miocene time (figs. 33 and 34). The Kronotsky terrane, a Late Cretaceous or Paleocene to Oligocene sequence of high alumina tholeiitic basalts, is inferred to be separate from the Hawaiian/Emperor seamounts due to the Maastrichtian age of the upper basalt layers of the Meiji seamount, the northwesternmost end of the seamount chain, found to the east of Kronotsky Peninsula. Although the geochemical analysis of the basalts was obtained from only five samples, it is interesting to note that the volcanic rocks are of the same age as the volcanic rocks of the western Aleutian arc.

The Kronotsky terrane approached the trench of the Sredinny Range volcanic arc during Oligocene and Early Miocene time with the Tyushevka Basin representing a narrow sedimentary trough that formed between the accretionary wedge and the approaching terrane. Deformation and thrust faulting of the rocks of the Eastern Kamchatka Basin and the Eastern Ranges occurred in Middle Miocene time when the terrane accreted into the trench. The buoyancy and size of the terrane, once introduced into the trench, led to a shift in the locus of subduction from the Eastern Kamchatka Basin and to the ensuing shift in the axis of volcanism to the current observed position of the extensive Quaternary volcanoes (fig. 34).

Figure 34 - Pliocene to recent tectonic evolution of Kamchatka Peninsula

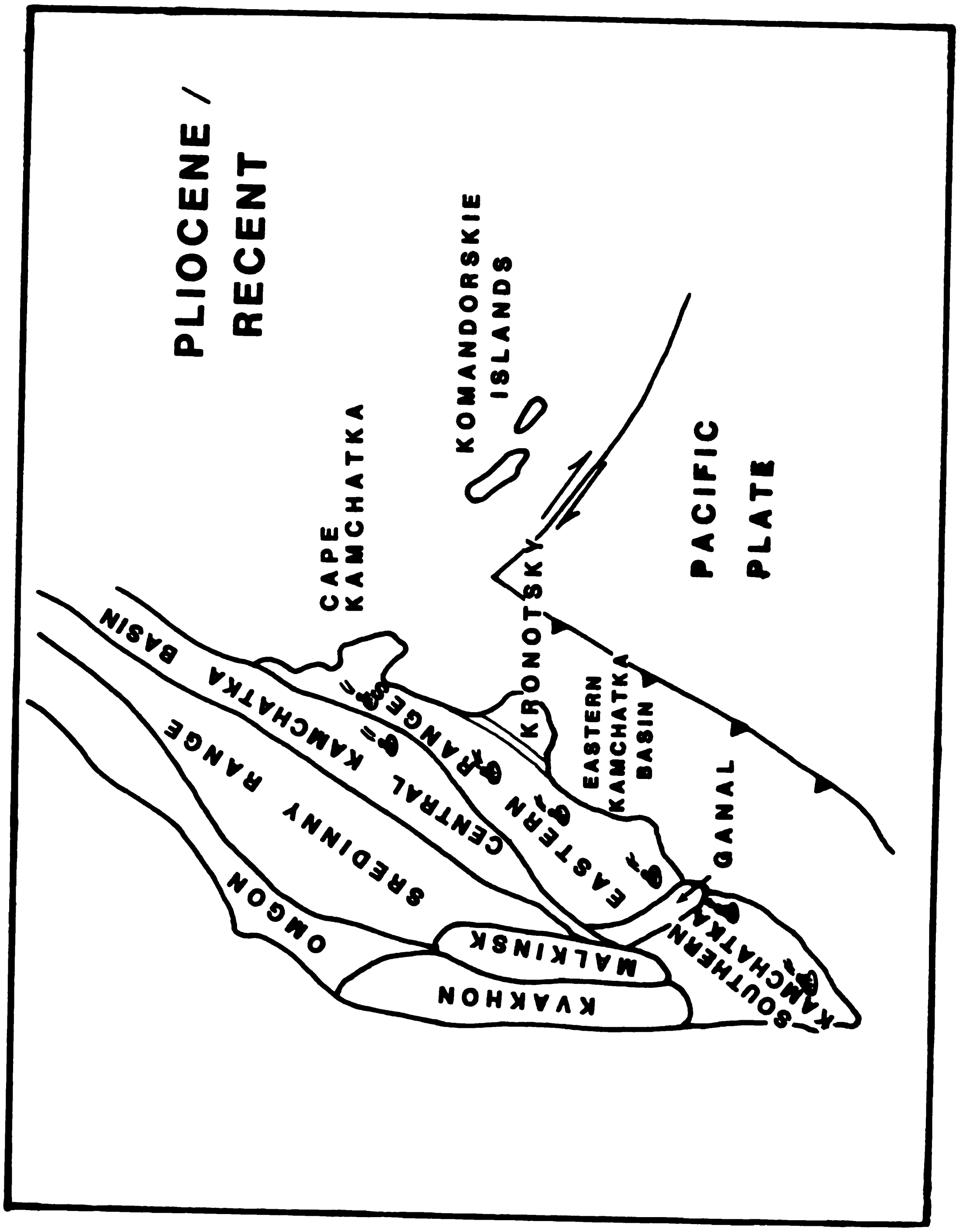

PLIOCENE / RECENT
KOMANDORSKIE ISLANDS
CAPE KAMCHATKA
PACIFIC PLATE
KRONOTSKY
EASTERN KAMCHATKA BASIN
CANAL
CENTRAL KAMCHATKA BASIN
EASTERN RANGE
SREDINNY RANGE
OMGON
MALKINSK
KVAKHON
SOUTHERN KAMCHATKA

Figure 34

CONCLUSIONS

Kamchatka Peninsula may be divided into ten tectonostratigraphic terranes by utilization of the methods of terrane analysis as outlined by Jones et al. (1983). Each of the terranes formed as a result of plate tectonic processes in oceanic tectonic environments. The primary element of the terranes is oceanic crust, including basalts, spilites and deepwater sediments sometimes associated with ultramafic rocks, that is found at the base of the stratigraphic sequence of seven of the ten terranes (Kvakhon, Omgon, Sredinny Range, Central Kamchatka Basin, Eastern Ranges, Southern Kamchatka and Cape Kamchatka). The Kronotsky terrane is probably the result of volcanic arc activity. The Ganal terrane is a fragment of oceanic lithosphere, either a portion of oceanic crust or seamount province, metamorphosed to a high degree. The Malkinsk terrane, represented by abundant granitic plutons and pelitic schists, is the result of subduction related plutonism and metamorphism. Five different volcanic arcs stitch together the terranes of Kamchatka. They are the Late Jurassic to Early Cretaceous Kvakhon/Omgon arc, the Late Cretaceous to earliest Tertiary Iruney and Eastern Ranges arcs, the Oligocene to Miocene Sredinny Range arc and the Quaternary Eastern Ranges/Southern Kamchatka arc. In between the time periods of volcanic activity, erosion and/or the deposition of clastic facies occurred. Ages of the terranes, the dates of their formation and periods of their development, occurred during Late Jurassic, Cretaceous and Tertiary time with a distinct possibility that some events may have occurred in Early and Middle Jurassic time. The development of the Kvakhon/Omgon arc and the Kolpakova series may have commenced in this time interval. The tectonic evolution of Kamchatka occurred in response to vectoral motions of oceanic plates in the Pacific Basin during Mesozoic and Cenozoic time. The oceanic plates include the Farallon, Izanagi, Kula and Pacific plates. Although the boundaries of these plates and Eurasia are not known with great accuracy as are the positions of the terranes of Kamchatka through Mesozoic and Cenozoic time, a correlation can be made between the oceanic plate motions and events of the terranes of Kamchatka. Finally, tectonic events of Kamchatka may be related to tectonic events of adjacent areas, besides the oceanic crustal plates, and include the Kuril and Aleutian Island arcs and the Sea of Okhotsk.

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